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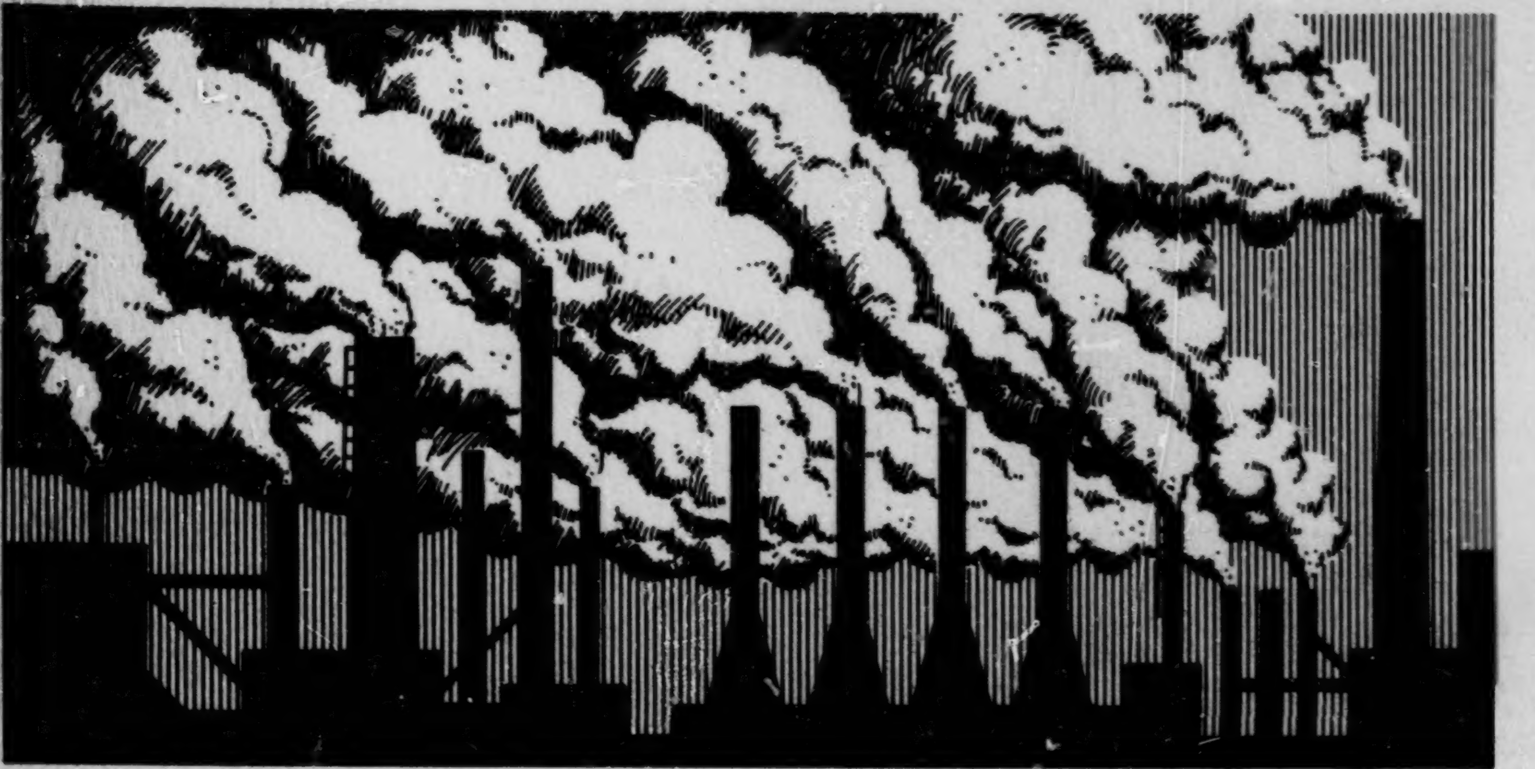

PARTICULATE POLLUTANT SYSTEM STUDY
VOLUME III - HANDBOOK OF EMISSION PROPERTIES

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16. Abstracts

A handbook is presented as part of the documentation for a study of particulate air pollution from stationary sources. The objective of the study was to identify, characterize, and quantify the particulate air pollution problem in the U. S. ~~This~~ document delineates the kind and number of stationary particulate sources, the chemical and physical characteristics of both the particulates and carrier gas emitted by specific sources, and the status of current control practices. The first three chapters of the handbook present general background information pertaining to source emission factors and emission rates effluent characteristics, and control technology. Chapter 4 discusses some of the more important chemical and physical properties of particulates and carrier gas emitted by industrial sources. The remaining chapters present discussions of the major industrial sources of particulate pollutants.

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PREFACE

This handbook was prepared for APCO under Contract No. CPA-22-69-104, which was monitored by Mr. Timothy Devitt and Mr. Don Felton.

The work was conducted in the Environmental Sciences Section of the Physical Sciences Division.

The handbook was written by Dr. A. E. Vandegrift, Project Director, and Dr. L. J. Shannon with the assistance of Dr. E. W. Lawless, Mr. P. G. Gorman, Mr. E. E. Sallee, and Miss M. Reichel.

Dr. Seymour Calvert and Mr. Paul L. Magill, consutants to MRI, made many valuable comments and contributions to this document. Dr. Larry Faith, Dr. Louis McCabe, and Dr. Frank Fowler also contributed to the program.

Approved for:

MIDWEST RESEARCH INSTITUTE

H. M. Hubbard, Director
Physical Sciences Division

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CHAPTER 1

INTRODUCTION

This handbook is presented as a part of the documentation for a NAPCA sponsored study, conducted at Midwest Research Institute, of particulate air pollution from stationary sources. The objective of the study was to identify, characterize, and quantify the particulate air pollution problem in the United States. This document delineates the kind and number of stationary particulate sources, the chemical and physical characteristics of both the particulates and carrier gas emitted by specific sources, and the status of current control practices. Details of the methodology employed to obtain the data reported in this handbook are presented in the final report for the project.

The first three chapters present general background information pertaining to source emission factors and emission rates, effluent characteristics, and control technology. The chapter on emission factors and rates (Chapter 2) outlines the methods used to calculate the total tonnage emitted by individual sources, and presents a ranking, on a tonnage emitted basis, of industrial sources of particulate pollutants. Chapter 3 highlights the general aspects of control equipment available for use on a source of particulate pollution. Distinguishing characteristics and general areas of application and ranges of performance of control devices are summarized in this chapter. Chapter 4 discusses some of the more important chemical and physical properties of particulates and carrier gas emitted by industrial sources. The discussion is focused primarily on the relationship of the effluent properties to control device selection and/or design. Chapter 5 presents a coding key for the tables of effluent characteristics presented in Chapters 6 - 24.

The remaining chapters (Chapters 6 - 24) present discussions of the major industrial sources of particulate pollutants. The industrial categories were selected on the basis of the ranking of tonnage emitted outlined in Chapter 2. The chapters on industrial sources delineate the production process, emission sources, emission rates, chemical and physical properties of the effluents, and control practices and equipment for each industrial category. Appendix A presents general cost information for control equipment. Miscellaneous emission data for minor sources are summarized in Appendix B.

This handbook constitutes a reference source for available information on the distinguishing features of the various particulate pollution sources and should be of value to air pollution regulatory agencies, control equipment manufacturers, and industrial concerns.

CHAPTER 2

EMISSION FACTORS AND RATES

2.1 INTRODUCTION

To assess the relative contributions of stationary sources of particulate air pollution, the major types and quantities of particulate pollutants emitted must be determined. Methods based on source emission factors are generally used to calculate quantities of particulates emitted for individual sources. Material balances and outlet grain loadings can also be used for these calculations.

The emission factor for stationary sources is a statistical average of the rate at which pollutants are emitted from the processing or burning of a given quantity of material. Ideally, emission factors should be related to aspects of system design, operating practices, and material processed to permit a definitive statement as to the total emissions characterizing a given source or plant producing a specified product. Unfortunately, the numerous and expensive stack testing studies needed to completely characterize a source have not generally been performed. Recourse must be made to existing data, and general comments presented on the probable influence of variables on emission factors. In some cases, especially industrial sources, the emission factor may be based upon tests conducted on only one installation or a few installations.

The source emission factors used in this handbook were compiled from an extensive literature survey and stack sampling data provided by air pollution control agencies and individual industrial companies. In most cases, a single number is presented for the emission factor for a specific source. These source emission factors are, in our judgment, the most accurate currently available. Details of the analysis of all available data for each specific source are presented in the final report for this project.1/

The industrial categories discussed in Chapters 6 - 24 were chosen from a ranking of sources based on the total tonnage of particulates emitted/year. The ranking of sources on the basis of tonnage emitted and its development are discussed in the following section.

2.2 EMISSION RATES OF INDUSTRIAL SOURCES

Important particulate pollutant sources based on the total tonnage emitted/year are presented in this section. The ranking was obtained by first listing possible sources and then investigating in detail a large enough segment to account for more than 99% of the total emissions on a mass basis.

Several different methods were used to calculate the total tonnage emitted by individual sources. These methods included the use of emission factors (both controlled and uncontrolled), material balances, and outlet grain loadings. The primary method used for establishing the tonnage emitted by an industry utilized uncontrolled emission factors. Total tonnage emitted by a given source was determined from four quantities: (1) an emission factor for the uncontrolled source; (2) the total tonnage processed/year by the source; (3) the efficiency of control equipment used; and (4) the percentage of production capacity equipped with control devices. The mathematical equation for the calculation is:

$$E = \frac{(P)(e_f)(1-C_c \cdot C_t)}{2,000} \quad (1)$$

where E = total particulate emissions for a source, tons/year

P = total production for the industry, tons/year

e_f = emission factor for uncontrolled source, pounds/ton

C_c = average efficiency of control equipment used in the industry for the specific source

C_t = amount of application of control in the industry (on a production capacity basis) for the specific source

C_cC_t = net control

Production figures were obtained primarily from government statistics. Efficiency of control equipment was determined from literature sources and information obtained from discussions with industrial contacts. The extent of application of control equipment in a given industry was found to be, in most cases, unobtainable from the open literature. There is some information as to the number of plants that have control equipment, but no information as to the production capacity of these plants or to the plants that do not have control equipment. Industry surveys were used to secure information on extent of control. Details of these surveys and the emission calculations are given in Reference 1.

Table 2-1 presents a ranking of important stationary industrial sources of particulate pollutants. The stationary sources represented in Table 2-1 were ranked by calculating the emissions from the primary pieces of processing equipment such as kilns, furnaces, reactors, and dryers. In several cases, we have included emissions for "secondary sources" which include crushing operations, materials handling, stockpiles, etc. The calculations involving these secondary sources are in general much less accurate than those involving the primary processing equipment because data on secondary sources are meager or nonexistent. The emission quantities listed for these secondary sources are at best order of magnitude calculations, and it is possible that secondary sources may emit as much or more particulate matter than the primary sources. Total emissions for an industry were obtained as a sum of the emissions from primary and secondary sources.

The leading sources are stationary combustion processes, crushed stone, agriculture and related operations, iron and steel, and cement. Emissions from residential and commercial combustion sources, field burning, and slash burning are not included in the totals shown in Table 2-1 for the stationary combustion processes, agricultural operations, and forest products categories. However, emissions from these processes are included in the individual chapters discussing these industries.

The reliability of the emission quantities in Table 2-1 was assessed by evaluating the reliability of each factor in Equation (1). The quantity of data available, the spread of the data, and the source of the data were considered in the evaluation. A reliability factor, ranging from 1 to 5 with 1 being the most reliable, was assigned to each factor. A composite rating, shown in the last column of Table 2-1, was then determined by averaging the ratings of the individual terms. In those cases where the emissions were calculated by a method other than Equation (1), a reliability rating was assigned directly to the final emission quantity.

More detailed discussions of manufacturing processes, particulate emission sources, particulate emission rates, effluent characteristics, and control practices and equipment for each industry category are presented in Chapters 6 - 24.

TABLE 2-1

MAJOR INDUSTRIAL SOURCES OF PARTICULATE POLLUTANTS
(Based on 1968 production data)

Source	Annual Tonnage P	Emission Factor Lb/Ton e_f	Efficiency[b] of Control C_c	Application[a] of Control C_t	Net[c] Control $C_c \cdot C_t$	Emissions Tons/Yr E	Reliability Rating[f]
1. Fuel Combustion							
A. Coal							
1. Electric Utility							
a. Pulverized	258,400,000 tons of coal	16A=190[d] lb/ton of coal	0.92	0.97	0.89	2,710,000	1
b. Stoker	9,900,000 tons of coal	13A=146 lb/ton of coal	0.80	0.87	0.70	217,000	1
c. Cyclone	28,700,000 tons of coal	3A=35 lb/ton of coal	0.91	0.71	0.64	182,000	1
			Total from Electric Utility Coal			3,109,000	
2. Industrial boilers							
a. Pulverized	20,000,000 tons of coal	16A=170[e] lb/ton of coal	0.85	0.95	0.81	322,000	2
b. Stoker	70,000,000 tons of coal	13A=133 lb/ton of coal	0.85	0.62	0.52	2,234,000	2
c. Cyclone	10,000,000 tons of coal	3A=31 lb/ton of coal	0.82	0.91	0.75	39,000	2
			Total from Industrial Coal			2,595,000	
B. Fuel Oil							
1. Electric Utility	7.18×10^9 gal.	0.010 lb/gal	0	0	0	36,000	2
2. Industrial							
a. Residual	7.51×10^9 gal.	0.023 lb/gal	0	0	0	87,000	2
b. Distillate	2.36×10^9 gal.	0.015 lb/gal	0	0	0	18,000	2
			Total from Fuel Oil			141,000	
C. Natural Gas & LPG							
1. Electric Utility	3.14×10^6 mil. scf	15 lb/mil. scf	0	0	0	24,000	2
2. Industrial	9.27×10^6 mil. scf	18 lb/mil. scf	0	0	0	84,000	2
			Total from Natural Gas & LPG			108,000	
		Total from Utility and Industrial Fuel Combustion				5,953,000	
2. Crushed Stone, Sand & Gravel							
A. Crushed Stone	681,000,000	17	0.80	0.25	0.20	4,554,000	4
B. Sand & Gravel	918,000,000	0.1	--	--	0	46,000	4
			Total from Crushed Stone, Sand & Gravel			4,600,000	
3. Operations Related to Agriculture							
A. Grain Elevators	177,000,000 tons grain handled		0.70	0.40	0.28	1,700,000*	3
B. Cotton Gins	11,000,000 bales	12 lb/bale	0.80	0.40	0.32	45,000	2
C. Feed Mills							
1. Alfalfa Mills	1,600,000 tons dry meal	50 lb/ton dry meal	0.85	0.50	0.42	23,000	2
2. Mills Other Than Alfalfa	8,364,000 tons	1% of production	0.85	0.50	0.42	49,000	2
			Total from Listed Agricultural Operations			1,817,000	

TABLE 2-1 (Continued)

Source	Annual Tonnage P	Emission Factor Lb/Ton e_f	Efficiency[b]/ of Control C_c	Application[a]/ of Control C_t	Net[c]/ Control $C_c \cdot C_t$	Emissions Tons/Yr E	Reliability Rating[f]/
4. Iron and Steel							
A. Ore Crushing	82,000,000 tons of ore	2 lb/ton of ore	0	0	0	82,000	4
B. Materials Handling	131,000,000 tons of steel	10 lb/ton of steel	0.90	0.35	0.32	446,000	4
C. Pellet Plants	50,000,000 tons of pellets	--	--	--	--	80,000*	4
D. Sinter Plants	51,000,000 tons of sinter						
1. Sintering Process		20 lb/ton of sinter	0.90	1.0	0.90	51,000	2
2. Crushing, Screening, Etc.		22 lb/ton of sinter	0.90	1.0	0.90	56,000	2
E. Coke Manufacture							
1. Beehive	1,300,000 tons of coal	200 lb/ton of coal	0	0	0	130,000	2
2. By-Product	90,000,000 tons of coal	2 lb/ton of coal	0	0	0	90,000	2
3. Pushing & Quenching	91,300,000 tons of coal	0.46 lb/ton of coal	--	--	--	21,000	3
F. Blast Furnace	88,800,000 tons of iron	130 lb/ton of iron	0.99	1.0	0.99	58,000	2
G. Steel Furnaces							
1. Open Hearth	65,800,000 tons of steel	17 lb/ton of steel	0.97	0.41	0.40	337,000	2
2. Basic Oxygen	48,000,000 tons of steel	40 lb/ton of steel	0.99	1.0	0.99	10,000	2
3. Electric Arc	16,800,000 tons of steel	10 lb/ton of steel	0.99	0.79	0.78	18,000	2
H. Scarfing	131,000,000 tons of steel	3 lb/ton of steel	0.90	0.75	0.68	63,000	3
			Total from Iron and Steel			1,442,000	
5. Cement							
A. Wet Process	43,600,000 tons of cement						
1. Kilns		167 lb/ton of cement	0.94	0.94	0.88	435,000	1
2. Grinders, Dryers, etc.		25 lb/ton of cement	0.94	0.94	0.88	65,000	3
B. Dry Process	31,000,000 tons of cement						
1. Kilns		167 lb/ton of cement	0.94	0.94	0.88	310,000	1
2. Grinders, Dryers, etc.		67 lb/ton of cement	0.94	0.94	0.88	124,000	3
			Total from Cement			934,000	
6. Forest Products							
A. Wigwam Burners	27,500,000 tons of waste	10 lb/ton of waste	0	0	0	132,000	2
B. Pulp Mills							
1. Kraft Process	24,300,000 tons of pulp						
a. Recovery Furnace		150 lb/ton of pulp	0.92	0.99	0.91	164,000	2
b. Lime Kilns		45 lb/ton of pulp	0.95	0.99	0.94	33,000	2
c. Dissolving Tanks		5 lb/ton of pulp	0.90	0.33	0.30	42,000	3
2. Sulfite Process	2,500,000 tons of pulp						
a. Recovery Furnace	833,000 tons of pulp	268 lb/ton of pulp	0.92	0.99	0.91	10,000	3
3. NSSC Process	3,500,000 tons of pulp						
a. Recovery Furnace	1,167,000 tons of pulp	24 lb/ton of pulp	0.92	0.99	0.91	1,000	3
b. Fluid-Bed Reactor	525,000 tons of pulp	533 lb/ton of pulp	0.70	1.00	0.70	42,000	3
4. Bark Boilers	--	--	--	--	--	82,000*	3
C. Particleboard, etc.	--	--	--	--	--	74,000*	4
			Total from Forest Products			580,000	
7. Lime							
A. Crushing, Screening	28,000,000 tons of rock	24 lb/ton of rock	0.80	0.25	0.20	264,000	3
B. Rotary Kilns	16,200,000 tons of lime	180 lb/ton of lime	0.93	0.87	0.81	294,000	2
C. Vertical Kilns	1,800,000 tons of lime	7 lb/ton of lime	0.97	0.40	0.39	4,000	2
D. Materials Handling	18,000,000 tons of lime	5 lb/ton of lime	0.95	0.80	0.76	11,000	3
			Total from Lime			573,000	

TABLE 2-1 (Continued)

Source	Annual Tonnage P	Emission Factor Lb/Ton e_f	Efficiency[b] of Control C_c	Application[a] of Control C_t	Net[c] Control $C_c \cdot C_t$	Emissions Tons/Yr E	Reliability Rating[f]
8. Primary Nonferrous Metals							
A. Aluminum							
1. Grinding of Bauxite	13,000,000 tons of bauxite	6 lb/ton of bauxite	--	--	0.80	8,000	3
2. Calcining of Hydroxide	5,840,000 tons of alumina	200 lb/ton of alumina	--	--	0.90	58,000	3
3. Reduction Cells							
a. H. S. Soderberg	800,000 tons of aluminum	144 lb/ton of aluminum	0.40	1.0	0.40	35,000	2
b. V. S. Soderberg	700,000 tons of aluminum	84 lb/ton of aluminum	0.64	1.0	0.64	10,000	2
c. Prebake	1,755,000 tons of aluminum	63 lb/ton of aluminum	0.64	1.0	0.64	20,000	2
4. Materials Handling	3,300,000 tons of aluminum	10 lb/ton of aluminum	0.90	0.35	0.32	11,000	4
			Total from Primary Aluminum			142,000	
B. Copper							
1. Ore Crushing	170,000,000 tons of ore	2 lb/ton of ore	0	0	0	170,000	3
2. Roasting	575,000 tons of copper	168 lb/ton of Cu	0.85	1.0	0.85	7,000	3
3. Reverb. Furnace	1,437,000 tons of copper	206 lb/ton of Cu	0.95	0.85	0.81	28,000	3
4. Converters	1,437,000 tons of copper	235 lb/ton of Cu	0.95	0.85	0.81	33,000	3
5. Materials Handling	1,437,000 tons of copper	10 lb/ton of Cu	0.90	0.35	0.32	5,000	4
			Total from Primary Copper			243,000	
C. Zinc							
1. Ore Crushing	18,000,000 tons of ore	2 lb/ton of ore	0	0	0	18,000	3
2. Roasting							
a. Fluid-bed	765,000 tons of zinc	2,000 lb/ton of Zn	0.98	1.0	0.98	15,000	3
b. Ropp, multi-hearth	153,000 tons of zinc	333 lb/ton of Zn	0.85	1.0	0.85	4,000	3
3. Sintering	612,000 tons of zinc	180 lb/ton of Zn	0.95	1.0	0.95	3,000	3
4. Distillation	612,000 tons of zinc	--	--	--	--	15,000*	4
5. Materials Handling	1,020,000 tons of zinc	7 lb/ton of Zn	0.90	0.35	0.32	2,000	4
			Total from Primary Zinc			57,000	
D. Lead							
1. Ore Crushing	4,500,000 tons of ore	2 lb/ton of ore	0	0	0	4,000	3
2. Sintering	467,000 tons of lead	520 lb/ton of lead	0.95	0.90	0.86	17,000	3
3. Blast Furnace	467,000 tons of lead	250 lb/ton of lead	0.85	0.98	0.83	10,000	3
4. Dross Reverb. Furnace	467,000 tons of lead	20 lb/ton of lead	--	--	0.50	2,000	3
5. Materials Handling	467,000 tons of lead	5 lb/ton of lead	0.90	0.35	0.32	1,000	4
			Total from Primary Lead			34,000	
			Total from Primary Nonferrous			476,000	

TABLE 2-1 (Continued)

Source	Annual Tonnage P	Emission Factor Lb/Ton e_f	Efficiency[b] of Control C_e	Application[b] of Control C_t	Net[c] Control $C_e \cdot C_t$	Emissions Tons/Yr E	Reliability Rating[f]
9. Clay							
A. Ceramic							
1. Grinding	4,740,000 tons	76 lb/ton	0.80	0.75	0.60	72,000	3
2. Drying	7,870,000 tons	70 lb/ton	0.80	0.75	0.60	110,000	3
B. Refractories							
1. Kiln-Fired							
a. Calcining	690,000 tons	200 lb/ton	0.80	0.80	0.64	25,000	3
b. Drying	1,032,000 tons	70 lb/ton	0.80	0.80	0.64	13,000	3
c. Grinding	3,440,000 tons	76 lb/ton	0.80	0.80	0.64	47,000	3
2. Castable	550,000 tons	225 lb/ton	0.90	0.85	0.77	14,000	3
3. Magnesite	130,000 tons	250 lb/ton	0.80	0.70	0.56	7,000	3
4. Mortars							
a. Grinding	130,000 tons	76 lb/ton	0.80	0.75	0.60	2,000	3
b. Drying	130,000 tons	70 lb/ton	0.80	0.75	0.60	2,000	3
5. Mixes	260,000 tons	76 lb/ton	0.80	0.75	0.60	4,000	3
C. Heavy Clay Products							
1. Grinding	4,740,000 tons	76 lb/ton	0.80	0.75	0.60	72,000	3
2. Drying	7,110,000 tons	70 lb/ton	0.80	0.75	0.60	99,000	3
			Total from Clay			467,000	
10. Fertilizer and Phosphate Rock	41,500,000 tons of rock						
A. Phosphate Rock							
1. Drying		12 lb/ton	0.94	1.0	0.94	14,000	2
2. Grinding		2 lb/ton	0.97	1.0	0.97	1,000	2
3. Materials Handling		2 lb/ton	0.90	0.25	0.22	30,000	4
4. Calcining	8,280,000 tons	40 lb/ton	0.95	1.0	0.95	8,000	3
B. Fertilizers							
1. Ammonium Nitrate	2,000,000 tons of granules	--	--	--	--	28,000*	4
2. Urea	1,000,000 tons of granules	--	--	--	--	10,000*	4
3. Phosphates							
a. Rock Pulverizing	17,000,000 tons of rock	6 lb/ton of rock	0.80	1.0	0.80	10,000	2
b. Acid-Rock Reaction	3,770,000 tons of P_2O_5	48 lb/ton of P_2O_5	0.95	0.95	0.90	9,000	2
c. Granulation and Drying, etc.	18,100,000 tons of granules	195 lb/ton	0.95	0.95	0.90	169,000	2
d. Materials Handling	--	--	--	--	--	18,000*	4
e. Bagging	9,000,000 tons of granules	--	--	--	--	4,000*	4
4. Ammonium Sulfate	2,700,000 tons of granules	--	--	--	--	27,000*	4
			Total from Fertilizers and Phosphate Rock			328,000	
11. Asphalt							
A. Paving Material	251,000,000 tons of material						
1. Dryers		32 lb/ton of material	0.97	0.99	0.96	161,000	2
2. Secondary Sources		8 lb/ton of material	0.97	0.99	0.96	40,000	2
B. Roofing Material	3,284,000 tons of asphalt						
1. Blowing		4 lb/ton of asphalt	--	--	0.50	3,000	4
2. Saturator		--	--	--	--	14,000*	4
			Total from Asphalt			218,000	

TABLE 2-1 (Continued)

Source	Annual Tonnage P	Emission Factor Lb/Ton e_f	Efficiency b/ of Control C_e	Application c/ of Control C_t	Net d/ Control $C_e \cdot C_t$	Emissions Tons/Yr E	Reliability Rating f/
12. Ferroalloys							
A. Blast Furnace	491,000 tons of ferroalloy	410 lb/ton ferroalloy	0.99	1.00	0.99	1,000	2
B. Electric Furnace	2,110,000 tons of ferroalloy	240 lb/ton ferroalloy	0.80	0.50	0.40	150,000	2
C. Materials Handling	2,710,000 tons of ferroalloy	10 lb/ton ferroalloy	0.90	0.35	0.32	9,000	4
			Total from Ferroalloys			160,000	
13. Iron Foundries							
A. Furnaces	18,000,000 tons of hot metal	16 lb/ton of metal	0.80	0.33	0.27	105,000	2
B. Materials Handling							
1. Coke, Limestone, etc.		5 lb/ton of metal	0.80	0.25	0.20	37,000	3
2. Sand	18,500,000 tons of sand	0.3 lb/ton of sand	0	0	0	1,000	?
			Total from Iron Foundries			143,000	
14. Secondary Nonferrous Metals							
A. Copper							
1. Material Preparation							
a. Wire Burning	300,000 tons insulated wire	275 lb/ton of wire	0	0	0	41,000	3
b. Sweating Furnaces	81,000 tons scrap	15 lb/ton of scrap	0.95	0.20	0.19	--	
c. Blast Furnaces	287,000 tons scrap	50 lb/ton of scrap	0.90	0.75	0.68	2,000	3
2. Smelting & Refining	1,170,000 tons scrap	70 lb/ton of scrap	0.95	0.60	0.57	17,000	2
			Total from Secondary Copper			60,000	
B. Aluminum							
1. Sweating Furnaces	500,000 tons scrap	32 lb/ton of scrap	0.95	0.20	0.19	6,000	4
2. Refining Furnaces	1,015,000 tons scrap	4 lb/ton of scrap	0.95	0.60	0.57	1,000	3
3. Chlorine Fluxing	136,000 tons Cl used	1,000 lb/ton Cl used	--	--	0.25	51,000	4
			Total from Secondary Aluminum			58,000	
C. Lead							
1. Pot Furnaces	53,000 tons scrap	0.8 lb/ton of scrap	0.95	0.95	0.90	--	
2. Blast Furnaces	110,000 tons scrap	190 lb/ton of scrap	0.95	0.95	0.90	1,000	2
3. Reverb. Furnaces	554,000 tons scrap	100 lb/ton of scrap	0.95	0.95	0.90	3,000	2
			Total from Secondary Lead			4,000	
D. Zinc							
1. Sweating Furnaces							
a. Metallic Scrap	58,000 tons of scrap	12 lb/ton of scrap	0.95	0.20	0.19	--	
b. Residual Scrap	210,000 tons of scrap	30 lb/ton of scrap	0.95	0.20	0.19	3,000	3
2. Distillation Furnace	233,000 tons Zn recovered	45 lb/ton of zinc	0.95	0.60	0.57	2,000	3
			Total from Secondary Zinc			5,000	
			Total from Secondary Nonferrous Metals			127,000	

TABLE 2-1 (Concluded)

Source	Annual Tonnage P	Emission Factor Lb/Ton e_f	Efficiency b/ of Control C_c	Application a/ of Control C_t	Net c/ Control $C_c \cdot C_t$	Emissions Tons/Yr E	Reliability Rating f/
15. Coal Cleaning							
A. Thermal Dryers	75,000,000 tons dried	--	--	1.0	--	94,000*	2
16. Carbon Black							
A. Channel Process	71,000	2,300	0	0	0	82,000	1
B. Furnace Process							
1. Gas	166,000	--	--	1.00	--	5,000*	2
2. Oil	1,180,000	--	--	1.00	--	6,000*	2
			Total from Carbon Black			93,000	
17. Petroleum							
A. FCC Units	1.10 x 10^9 bbl. of feed	--	--	1.0	--	45,000*	3
18. Acids							
A. Sulfuric							
1. New Acid	1,000,000 tons of 100% H_2SO_4	5 lb/ton of 100% H_2SO_4	--	0	0	2,000	1
a. Chamber	27,000,000 tons of 100% H_2SO_4	2 lb/ton of 100% H_2SO_4	0.95	0.90	0.86	4,000	2
b. Contact							
2. Spent-Acid Concentrators	11,000,000 tons of spent acid	30 lb/ton of spent acid	0.95	0.85	0.80	8,000	4
B. Phosphoric							
1. Thermal Process	1,000,000 tons of P_2O_5	134 lb/ton of P_2O_5	0.97	1.0	0.97	2,000	1
			Total from Acids			16,000	
			TOTAL FROM MAJOR INDUSTRIAL SOURCES			18,056,000	

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* See specific industry section of Volume I for method of calculating quantity emitted.

a/ Application of Control is defined as that fraction of the total production which has controls.

b/ Efficiency of Control is defined as the average fractional efficiency of the control equipment, prorated on the basis of production capacity.

c/ Net Control is defined as the overall level of control, and is the product of the application of control multiplied by the efficiency of control.

d,e/ Average Ash Content of Coal Used, determined by phone survey (see Volume I - Section 5):

Type Boiler	(d) Elec. Util.	(e) Industrial
Pulverized	11.0%	10.6%
Stoker	11.2%	10.8%
Cyclone	11.6%	10.3%

f/ Reliability rating is indicative of the reliability of the Emissions quantity. Ratings range from 1 to 4 with 1 being the most reliable.

REFERENCES

1. "Particulate Pollutant System Study, Vol. I, Mass Emissions," Midwest Research Institute, NAPCA Contract No. CPA 22-69-104, May 1971.

CHAPTER 3

CONTROL EQUIPMENT

3.1 INTRODUCTION

Equipment available for the control of particulate matter consists of cyclones, wet scrubbers, electrostatic precipitators, and fabric filters. Afterburners may also be used for removal of combustible gases and particulates. The chapters in this handbook discuss the application, advantages, and disadvantages of these devices in each of the major industrial categories of particulate pollution.

The preliminary consideration in selection of the different types of devices is probably most dependent on the volume of gas to be treated. Knowing this, rough cost estimates can be made on the basis of cost figures and equations presented in Appendix A.1/ Appendix A includes figures illustrating purchase cost, installed cost, and annualized cost of operation plus equations for annual operating and maintenance costs. It should be borne in mind that these costs can vary considerably for any specific application, as is noted in some of the chapters of this handbook.

Specifications for a particular application require considerably more information than gas volume. Particle and carrier gas characteristics are needed including particle size concentration (average and range), particle size distribution, particle density, particle resistivity, gas flow rate, gas temperature and moisture content, and other important properties such as corrosivity or flammability.

The usual objective of installing pollution control equipment is concerned with the quantity or concentration of particulate matter that will be emitted. Therefore, the specifications will usually stipulate the maximum allowable emissions as a quantity in lb/hr or as a concentration in grains/scf. This will set the efficiency for which the control equipment must be designed, based on given inlet conditions. An indication of the relative efficiency of various collection devices, as a function of particle size, is shown in Figure 3-1.3/ These curves were obtained using one standard test dust which compares to a typical fly ash.

The opacity of the emission is usually also an important aspect of the equipment performance. Opacity is related to the outlet concentration

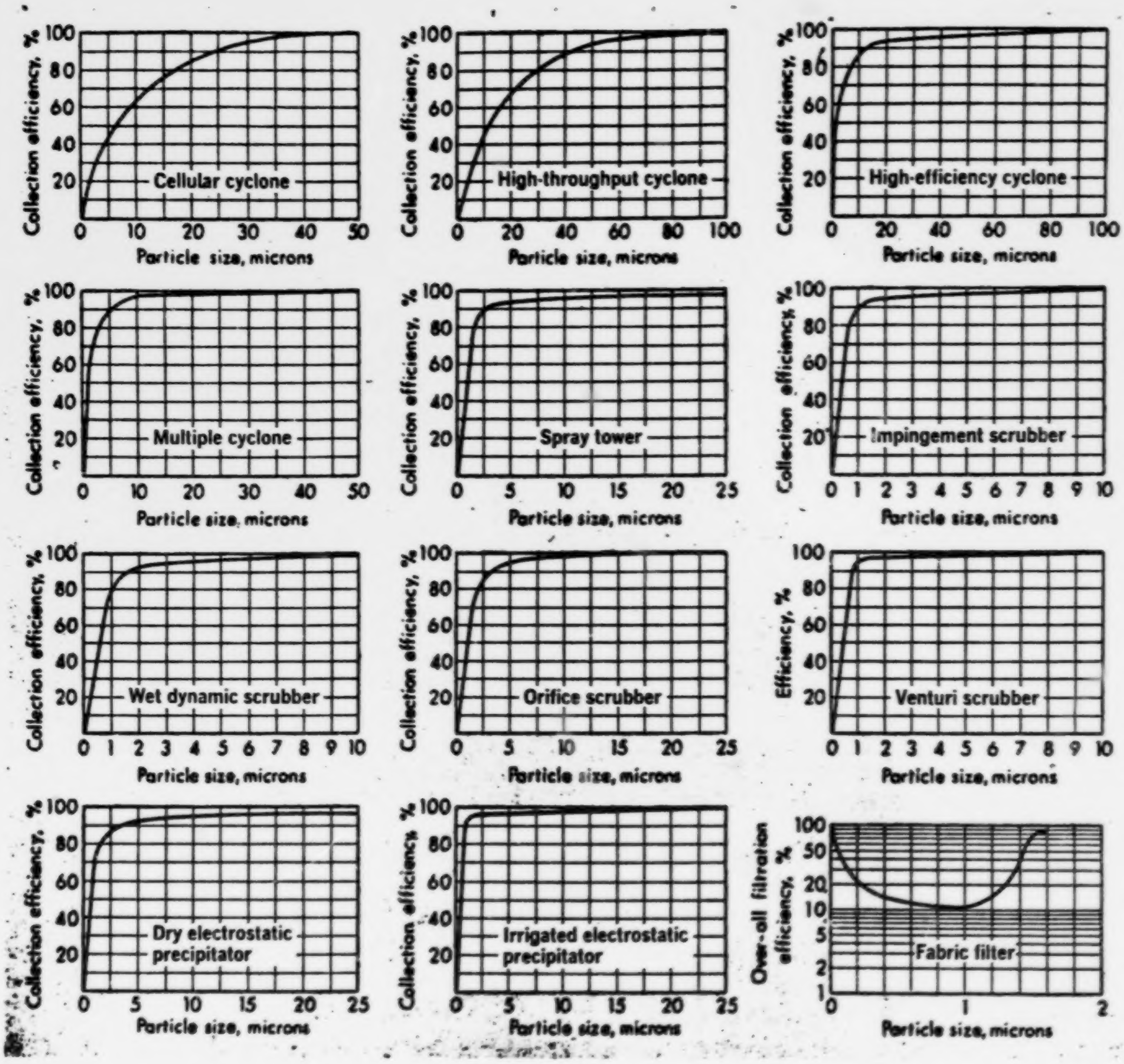

Figure 3-1 - Efficiency Curves for Various Types of Dust Collecting Equipment[3/]

of the particulate matter. It should be remembered that the finer particles, which are the most difficult to collect, affect the light scattering properties of the stack effluent. This is one of the reasons that the inlet particle size distribution is so important. If the control equipment must provide a clear stack, the outlet concentration to be specified may be lower than would otherwise be required. The maximum permissible concentration for fly-ash emissions from power plants is of the order of 0.02 - 0.03 grain/scf for the discharge to be invisible.[4] Maximum concentrations for other industry effluents are presented in some of the industry chapters of this handbook.

A brief description of each of the general types of control devices is presented below to acquaint the reader with each and to point out those industries and processes that utilize each type. A more complete description of each of the devices and treatment of theoretical considerations may be found in References 1, 2 and 3 plus many of the references given in the bibliographies following each industry chapter.

3.2 CYCLONES

Cyclonic collectors are round conically shaped vessels in which the gas stream enters tangentially and follows a spiral path to the outlet. The spiral motion produces the centrifugal forces that cause the particulate matter to move toward the periphery of the vessel and collect on the walls and fall to the bottom of the vessel.

The centrifugal force is the major force causing separation of the particulate in a cyclone separator. This force (F_c) is equal to the product of the particulate mass (M_p) and centrifugal acceleration (V_p^2/R), where V_p is the particle velocity and R is the radius of motion (curvature).

$$F_c = (M_p)\left(\frac{V_p^2}{R}\right)$$

The centrifugal forces cause the particles to move outward toward the wall of the cyclone. However, this movement of the particle through the gas stream is opposed by frictional drag on the particle caused by the relative motion of the particle and gas. The frictional drag (F_f) is directly proportional to the product of (C_f), a drag coefficient, the projected cross-sectional area of the particle (A_p), particle density (p), the square of the particle velocity relative to the gas stream (V_r^2), and an inverse function of the acceleration due to gravity (g).

$$F_f = (C_f)(A_p)(p)(V_r^2)/2g$$

The centrifugal and frictional forces, plus the force of gravity, combine to determine the collection efficiency. This collection efficiency increases with:

(1) dust particle size
(2) particle density
(3) gas velocity
(4) cyclone body length
(5) smoothness of cyclone wall

Although efficiency increases with increasing gas velocity, this is at a lower rate than that at which the pressure drop increases. For a given cyclone and dust combination, an optimum velocity exists, beyond which turbulence increases more rapidly than separation efficiency, and efficiency decreases.[1/]

The cyclonic collectors are generally of two types: the large diameter, lower efficiency cyclones, and the smaller diameter, multitube high-efficiency units. The larger cyclones have lower efficiencies especially on particles less than about 50 μ. However, they have low initial cost and usually operate at pressure drops of 1-3 in. of water. The multitube cyclones are capable of efficiencies exceeding 90% but the cost is higher and their pressure drop is usually 3-5 in. of water. They are also more susceptible to plugging and erosion.

The larger cyclones are often used as a part of the process when the gas stream is heavily laden with part of the product such as in coal dryers, alfalfa dehydrators and milling operations. They are widely used in grain elevators, sawmills, asphalt plants and detergent manufacture.

3.3 WET SCRUBBERS

Wet collectors use water "sprays" to collect and remove particulate matter. There are many variations of wet collectors but they may generally be classified as low or high energy scrubbers. Low energy scrubbers of 1-6 in. of pressure drop may consist of simple spray towers, packed towers or impingement plate towers. Water requirements may run 3-6 gal/1,000 cu ft. of gas and collection efficiencies can exceed 90-95%. The lower energy scrubber finds frequent application in incinerators, fertilizer manufacturing, lime kilns, and iron foundries.

The high energy scrubber, or Venturi, imparts high velocity to the gas stream by means of converging-diverging duct section, and contacts the stream with injected water. The high velocities provide increased collection efficiency, up to 99.5%, but the pressure drop may range from 10-60 in. of water. This requires a draft fan with high power input. The Venturi scrubber is often used in conjunction with steel furnaces, pulp mills and foundry cupolas.

The wet scrubbers can provide high collection efficiency but may involve treatment of liquid wastes with settling ponds. They also saturate the gas stream and produce a resultant steam plume.

The principal mechanisms involved in wet scrubbing are: (1) increasing the size of the particles by combination with liquid droplets thereby increasing their size so they may be collected more easily, and/or (2) trapping them in a liquid film and washing them away.

Dust collection efficiency is believed by some investigators to be directly related to contacting power and the properties of the particulate matter. Contacting power is that portion of useful energy expended in producing contact of the particulate matter with the scrubbing liquid, as well as in producing turbulence and mixing in the scrubber device. The contacting power represents the kinetic energy or pressure head loss across the scrubber, kinetic energy or pressure head drop of the scrubbing liquid, and other forms of energy dissipated in the gas stream such as sonic energy or energy supplied by a mechanical rotor. This means that the higher the power imput, the higher is the efficiency. However, the efficiency is also a function of the particulate matter properties and the smaller particles require higher power input than larger particles.1/

3.4 ELECTROSTATIC PRECIPITATORS

The operating principle of electrostatic precipitation requires three basic steps:

(1) Electrical charging of the suspended particulate matter.

(2) Collection of the charged particulate matter on a grounded surface.

(3) Removal of the particulate matter from the collecting surfaces by mechanical scrubbing or flushing with liquids.

The electrical charging is accomplished by passing the suspended particles through a high-voltage, direct-current corona. Peak voltage requirements usually range from 30 to 100 kilowatts. Gas velocities range from 3 to 15 ft/sec. This low linear velocity promotes deposition and minimizes re-entrainment. However, this also means that the precipitators will be large in size, or cross-sectional area, to achieve the low gas velocities. Uniform flow distribution is also an important factor that must be considered in design of ductwork.

The collection efficiency of electrostatic precipitators is expressed by the Deutsch equation as:[2]

$$E = 1-\epsilon^{-wA/Q}$$

where

E = weight fraction of dust collected

w = migration velocity of dust particle toward the collecting electrode, ft/sec

A = area of collecting electrode, ft^2

Q = gas flow rate, acf/sec

This equation shows the exponential relationship of efficiency to the area of the collecting electrode. Thus, moderate increases in collector efficiency for an existing unit may require a rather large increase in collecting surfaces.

The proper operation of an electrostatic precipitator is dependent on the electrical resistivity of the particles. Pre-conditioning with water sprays may be required to impart beneficial resistivity character to the particles. Proper control of operating voltages must also be provided if efficient particulate removal is to be maintained. The precipitator generally has high initial cost but it is capable of high collection efficiency, exceeding 99%, at a pressure drop less than 0.5 in. of water.

Electrostatic precipitators have been used extensively for many years to reduce particulate emissions from coal-fired power plants. These units handle very large gas volumes with low pressure drops. They have also been applied in steel mills to clean the gases from blast furnaces and basic oxygen furnaces, and in cement plants, pulp mills, and sulfuric acid plants.

3.5 FABRIC FILTERS

Fabric filter systems, i.e., baghouses, usually consist of tubular bags made of woven synthetic fabric or fiberglass, in which the dirty gases pass through the fabric while the particles are collected on the upstream side by the filtering action of the fabric. The dust retained on the bags is periodically shaken off and falls into a collecting hopper for removal.

Fabric filters usually provide very high collection efficiencies, exceeding 99.5%, at pressure drops usually ranging from 4-6 in. of water. The amount of filter area required is often based on an air-to-cloth ratio of 1.5-3.0 cu ft/min of gas/sq ft of cloth. The maximum operating temperature for a baghouse is 550°F using fiberglass bags. However, there may also be a minimum temperature limitation so as to maintain the gas temperature 50°F to 75°F above the dew point. Inlet dust loadings range from 0.1 to 10.0 grains/cu ft of gas. Higher concentrations in some industries are removed by a precleaning device, such as a low efficiency cyclone.

Baghouses do provide the high collection efficiency at moderate pressure drop but initial cost is relatively high especially when precooling systems are required. The baghouses also may be large and take up considerable space. They frequently entail high maintenance costs for bag replacement. However, replacement of bags need not impair baghouse operation if the unit is compartmented so that one section can be taken out of service for maintenance while the others continue to operate.

The baghouse has found wide application in many industries, including mining operations, food processing, grain elevators, soap and detergents, plastics manufacture and numerous others. Some of the industries that employ large baghouse operations are carbon black, cement, electric arc furnaces, foundry cupolas and nonferrous smelting operations.

3.6 MIST ELIMINATORS

One of the most commonly used type of mist eliminators is the mesh filter which consists of an evenly spaced knitted wire or plastic mesh, usually mounted in horizontal bed. Rising mist droplets strike the wire surface, flow down the wire to a wire junction, coalesce, and flow to the bottom surface of the bed, where the liquid disengages in the form of large droplets and returns by gravity to the process equipment.1/

Operating pressure drop is usually less than 1 in. of water with gas velocities of 10 to 15 ft/sec. Advantages in the use of this type of collector are low initial cost, low maintenance, high removal efficiency and recovery of valuable products without dilution.[1/] However, these units should not be used in services where the material can cause plugging of the mesh unless provision is made for flushing out accumulated solids.

Another type of mist eliminator consists of packed beds of fibers. These may operate at velocities ranging from 5 to 90 ft/sec and, therefore, have correspondingly higher pressure drops of 5 to 15 in. of water. Collection efficiencies may be in excess of 99% on particles.[1/]

Other types of mist eliminators are impingement baffle mist eliminators and packed bed mist eliminators which may not achieve efficiencies as high as those discussed above but do prevent loss or carryover of larger droplets.

3.7 AFTERBURNERS

Afterburners are gas cleaning devices which use a furnace for the combustion of gaseous and particulate matter. Combustion is accomplished either by direct flame incineration or by catalytic combustion.

The disposal of particulate matter by combustion is limited to residue-free vapors, mists and particulate matter which is readily combustible, as well as to particle sizes which require short furnace retention time and small furnace size. Afterburners are usually used to dispose of fumes, vapors, and odors when relatively small volumes of gases and low concentrations of particulate matter are involved.[1/]

Advantages of the direct flame incineration afterburner include: (1) high removal efficiency of submicron odor-causing particulate matter; (2) simultaneous disposal of combustible gaseous and particulate matter; (3) compatibility with existing combustion equipment; (4) relatively small space requirements; (5) simple construction; and (6) low maintenance.

Disadvantages include: (1) high operational costs including fuel and instrumentation; (2) fire hazards; and (3) excessive weight.

Advantages of the catalytic afterburner include: (1) reduced fuel requirements; and (2) reduced temperature, insulation requirements and fire hazards.

Disadvantages of catalytic afterburners include: (1) high initial cost; (2) sensitivity to catalytic poisoning; (3) inorganic particles must be removed and organic droplets must be vaporized before combustion to prevent damage and plugging of the catalyst; and (4) catalysts may require frequent reactivation.

Afterburner systems have been used successfully in many processes including asphalt blowing and saturating, paint baking, coffee roasting, food processing, Kraft paper manufacture, paint and varnish cooking and wire enameling.

The use of afterburners in conjunction with paint baking operations may allow recirculation of the combustion gases to the oven or recovery by heat exchangers. Fuel savings from the use of heat of combustion of the paint solvent vapors may be large enough to provide a 50% return on investment in the case of catalytic combustion.1/

REFERENCES

1. U. S. Department of Health, Education and Welfare, Control Techniques for Particulate Air Pollutants, Washington, D. C., 1969.

2. U. S. Department of Health, Education and Welfare, Air Pollution Engineering Manual, Cincinnati, Ohio, 1967.

3. Sargent, Gordon D., "Dust Collection Equipment," Chemical Engineering, January 1969.

4. White, Harry J., "Characteristics of Particulate Matter," Industrial Water and Wastes Magazine.

CHAPTER 4

EFFLUENT CHARACTERISTICS

4.1 INTRODUCTION

The severity of the problems associated with sources of particulate air pollution is dependent on the total amount or rate of emission and the physical and chemical characteristics of the emissions. Furthermore, the intelligent selection or design of dust collection equipment must be based on particle and carrier gas characteristics.

Important effluent characteristics which define the objectionable aspects of a pollution source include: (1) particle size distribution; (2) toxicity; (3) corrosivity; (4) soiling potential; and (5) optical properties. Particle and carrier gas properties that are important for control device selection or design include: (1) particle size distribution and shape; (2) particle density; (3) electrical resistivity; (4) volumetric flowrate; (5) gas temperature; and (6) humidity.

Some of the more important particulate and carrier gas characteristics are discussed in more detail in the following sections. The discussion will focus primarily on the relationship of the effluent properties to control device selection and/or design.

4.2 PARTICULATE CHARACTERISTICS

4.2.1 Particle Size

Information on particle size distribution in the gas stream is important in the proper selection of gas cleaning equipment. Particles larger than about 10 μ may be removed in inertial and cyclone separators and simple, low-energy wet scrubbers. Particles smaller than 10 μ require either high-efficiency (high-energy) wet scrubbers, fabric filters, or electrostatic precipitators.

Particle size in general cannot be specified uniquely by a single parameter. For irregular dust particles, the average dimension along three mutually perpendicular axes may be used, or the diameter of a sphere having the same volume or the same surface area as the particle may be chosen. Obviously, the more irregular the shape of the particles, the greater will be the variations in equivalent diameters. For extremely irregular particles like plates, rods, or stars, some other measure, such as specific surface or settling rate, will usually be more significant. In many gas cleaning processes the settling velocity has direct physical meaning, independent of particle structure, and is preferred to equivalent diameter.

Determination of particle size cannot be unique except for the special case of spherical particles. For all other cases, the results will depend on the experimental method used. Methods for determining particle size and particle size distribution may be classified as follows:

4.2.1.1 Sieve Analysis: Used for relatively coarse particles above 44 μ, corresponding to a 325 mesh screen.

4.2.1.2 Microscopic Analysis: The maximum resolving power of optical microscopes permits determination of particles down to about 0.5 μ. The much greater resolution of electron microscopes extends this lower limit to about 0.01 μ.

4.2.1.3 Sedimentation Analysis: This method is based on measurement of settling rate of particles in fluids. It gives settling velocities directly and equivalent diameters indirectly, based on known or assumed laws of the flow resistance or drag of the particles. Stokes' diameter is determined by this method, which is useful for particles in the range of about 0.5 to 50 μ.

4.2.1.4 Elutriation Analysis: This method is based on separation of particles in vertically rising fluids. Fine particles above a certain size cutoff point are carried upward with the rising fluid, and coarser particles below the cutoff point fall to the bottom of the elutriation chamber. A series of graded elutriation chambers may be used to separate particles into a series of size classes.

4.2.1.5 Centrifugal Analysis: Similar in principle to sedimentation but uses centrifugal forces, which may be as high as one million times gravity in the best ultracentrifuges. This extends the lower particle size limit down to giant molecules, or to about 0.01 μ.

4.2.1.6 Impaction Methods: Particles are deposited on a plate surface by impaction from an air jet. A series of graded impactors, the so-called cascade impactor, may be used to separate particles into size classes.

4.2.1.7 Photometric Methods: These methods are based on scattering or absorption of light, both of which depend on particle size. This method is most useful for fine particles below a few microns in size. Lower limit by the best techniques is about 0.03 μ for monodisperse or uniform particle size dispersions.

4.2.1.8 Miscellaneous Methods: Gas absorption methods, air permeability, X-ray diffraction.

No universal method or apparatus for particle size determination is possible, even in principle. For gas-cleaning applications, the sedimentation and elutriation methods have very definite advantages because they give results in terms of settling velocity or Stokes' diameter. But these methods usually necessitate redispersion of collected particle samples, which may be difficult, and any agglomerates present in the original aerosol cannot be reproduced in the particle size equipment. Another problem connected with sizing of industrial aerosols is the difficulty of procuring representative samples from the field because of the very large gas flows and variable conditions that characterize most industrial gas-cleaning situations.

The Bahco centrifugal dust classifier is used extensively for routine measurements by control device manufacturing companies. This instrument uses a form of centrifugal elutriation. Dust is fed into an air stream in the annular space between parallel rotating plates and in each stage the dust is divided into two fractions, one deposited on the periphery of the wheel and the other carried forward. By varying the air velocity a number of fractions can be collected. Instruments of this type require careful adjustment to ensure a good separation.[1]

Generally, the purpose of a particle size measurement is to discover the true frequency distribution of particle size. The observed distribution serves as basic data from which may be derived certain representative constants, for example, the median size. Modified relative frequency distributions can also be obtained by transformation; for example, percent by weight from percent by number. Adequate presentation of data is important to facilitate utilization.

Tabular and graphical forms can be used. A table can list size versus one of many ways of expressing distribution; for example, size frequency or size cumulation. It is essential to specify which weighting process is employed since distributions are generally radically different (e.g. number-size and weight-size distributions).[5]

Graphical methods for presenting size distributions are: (1) histograms, (2) size frequency curves and (3) cumulative plots. Cumulative plots are used extensively and their interpretation and comparison can be enhanced by using the generally applicable log-normal distribution plot or one of its modifications.[5] Figure 4-1 illustrates a log-normal distribution plot for particulates emitted from a kraft pulp mill recovery furnace.

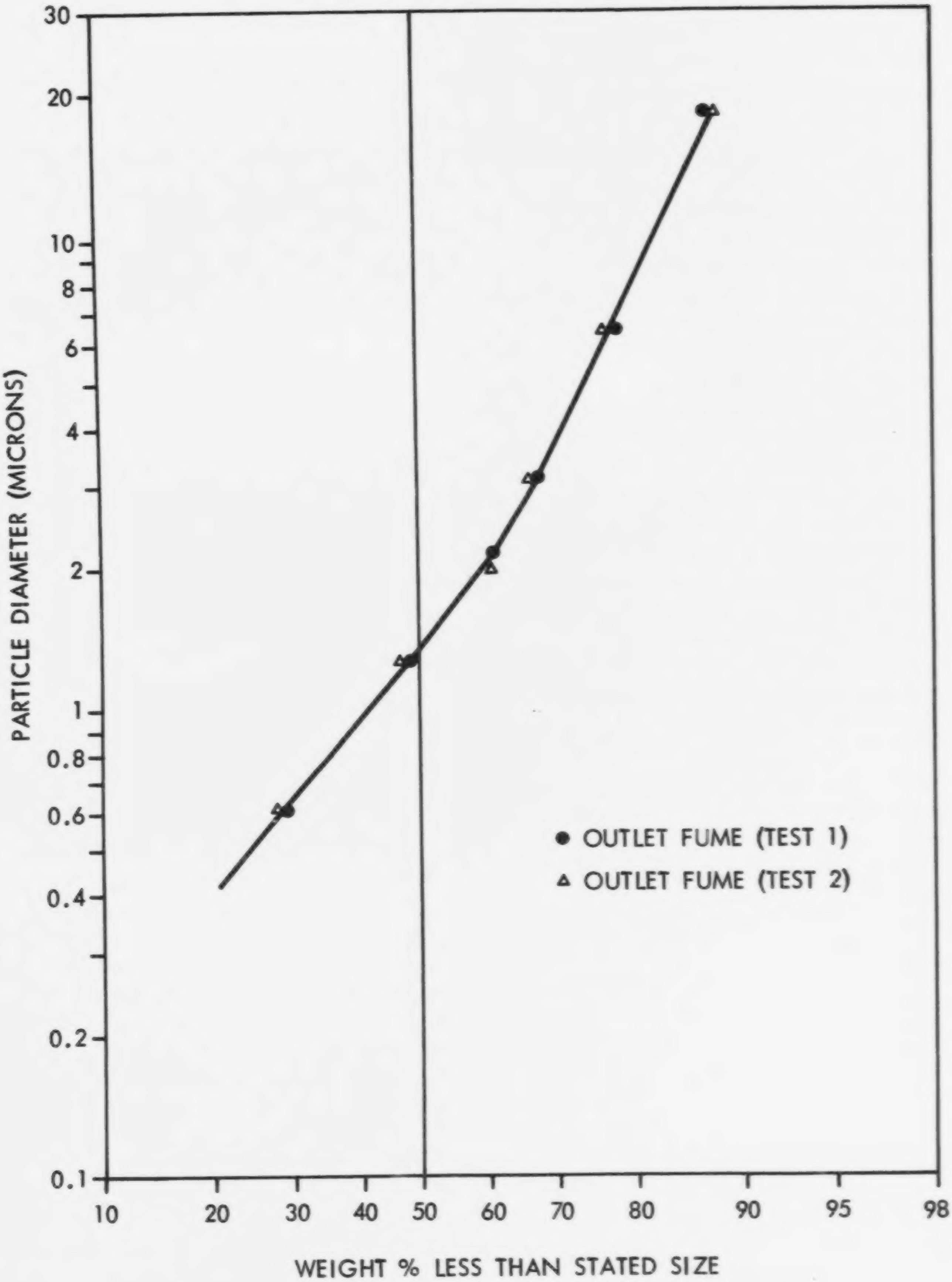

Figure 4-1 - Average Size Distributions of Outlet Fume - Kraft Mill Recovery Furnace

Log-normal size distributions are defined by two parameters: (1) the intercept of the cumulative curve with the 50% probability mean diameter, and (2) the polydispersity factor (geometric deviation) defined as:

$$\text{Polydispersity factor} = \frac{\text{intercept at 50\% probability}}{\text{intercept at 15.87\% probability}}$$

A completely monodisperse aerosol has a polydispersity factor of one.

Figure 4-1 shows that 50% of the outlet fume is composed of particles smaller than 1.4 μ in diameter. The polydispersity factor is 4.2.

Comprehensive discussions of particle size measurement, interpretation, and application are given in References 1, 5 and 6. Readers interested in more detail are directed to these sources.

4.2.2 Particle Shape

As noted above, particle size analysis does not account for the multiplicity of particle shapes. Particle shapes of aerosols are of many types, from simple spheres to complex stars and chainlike aggregates. Fogs, mists, and some smokes are composed of spherical liquid or tarry droplets. Many fly ash particles, produced in the combustion of pulverized coal, are hollow spheres or cenospheres, frequently with much smaller satellite particles attached to their surfaces. Dust particles usually are irregular in shape as the result of multiple fractures that occur in crushing or grinding. Many metallurgical fumes have a starlike or platelike shape; others are needlelike and tend to form agglomerated chains.

Particle shape and surface condition influence handling characteristics, chemical reactivity, adsorption potential, and flammability limits among other particulate properties.

4.2.3 Solids Loading

Solids loading is a measure of particulate concentration in the gas stream. While it is not strictly a particulate property, it is included in this category for ease of discussion. Solids loading or grain loading is usually expressed in grains per cubic foot (1 grain = 1/7,000 lb). Grain loading and particle size often dictate the choice of control equipment. Very high grain loadings might require the use of a series control device configuration to meet air pollution regulations (i.e., cyclone followed by an electrostatic precipitator or a baghouse).

4.2.4 Electrical Properties

The most important electrical properties of particulates are their electric charge and conductivity. Practically all natural or industrial dusts are electrically charged to an appreciable degree. The fractions of positively and negatively charged dust are generally equal, so that any given dust suspension is, as a whole, electrically neutral.

4.2.4.1 Particle Resistivity: In the electrical precipitation method for gas cleaning, the particle deposits on the collection surfaces of precipitators must possess at least a small degree of electrical conductivity. Theory and experience indicate that the critical or minimum value of particle conductivity for normal precipitator performance is about 0.5 x 10^{-10} inverse ohm-cm, or as more commonly expressed, a maximum resistivity of 2 x 10^{10} ohm-cm (measured in situ).

In precipitator operation, high particle resistivity is usually manifested by disturbed electrical conditions in the form of excessive sparking with moderately lowered voltages, or by excessive current with greatly lowered voltages. These effects in turn cause loss of precipitator efficiency, the loss in performance increasing with resistivity. When resistivity exceeds about 10^{11} ohm-cm it becomes very difficult to achieve reasonable efficiencies with precipitators of conventional design. Special types of precipitators must then be used, or, more commonly, measures must be taken to reduce resistivity.3/

There are a number of factors and combinations of factors which influence the apparent resistivity of particulates. Among those particle characteristics which may be important are particle size distributions, shape, particle temperature, surface energy characteristics, packing configuration, and chemical composition. Carrier gas characteristics include chemical composition and temperature.

Most liquid particles and certain types of solid particles are intrinsically conducting and, therefore, cannot cause difficulty because of high resistivity. Most of the dusts and fumes in industrial precipitation applications, however, originate from furnace, smelting, drying, or calcining operations and are composed of silicates, metallic oxides, and similar inorganic compounds. Many of these materials in the pure dry state are among the best insulators known and, therefore, might be expected to cause trouble in precipitators. However, moisture and chemical impurities present in the gases and adsorbed on the particles provide at least part of the trace conductivity required. In other cases the gas temperature may be sufficiently high to ensure adequate conductivity in the particles by the temperature conduction effect. Low moisture, absence of certain specific chemical impurities, and temperatures in the range of 250°F to 450°F are likely to cause high resistivity particles.[3]

4.2.4.1.1 Conduction mechanisms: The electrical conductivity of a bulk layer of particles depends on both surface and volume factors. In surface conduction, electrical charges are carried in the surface moisture and chemical films adsorbed on the particles. These films usually differ both physically and chemically from the interiors of the particles owing to adsorption phenomena. Volume conduction, or the motions of electrical charges through the interiors of the particles, depends, on the other hand, on the composition and temperature of the particles. Volume conduction also involves ancillary factors, such as compression of the particle layer, particle size and shape, and surface properties.[3]

Volume conduction in semi-insulating mineral particles may be either ionic or electronic. The most common examples of ionic conductors are metallic halides, such as sodium chloride or silver bromide, and are of little importance in electrical precipitation. Electronic conduction occurs in many materials, such as metallic oxides and silicates, which are of primary interest in industrial gases. For the metallic oxides and the silicates the resistance to volume conduction decreases with rising temperatures in the following manner:

$$\rho = A \exp E/kT$$

where ρ = resistivity

A = constant

E = electron activation energy

k = Boltzman's constant

T = temperature

Volume conduction is thought to be the predominant mode at temperatures above approximately 300-350°F. At lower temperatures, volume conduction becomes insignificant. It appears that the volume conductivity of dusts and fumes is caused by temperature excitation of internal electrons. Field measurements confirm the increase in particle conductivity and the improved performance of precipitators collecting these materials at higher temperatures.

Surface conduction usually predominates for semi-insulating particles in the temperature range below about 300°F. As previously noted, conduction at these lower temperatures occurs primarily through adsorbed moisture and chemical films on the particles. Moisture is present naturally in most industrial gases controlled by electrical precipitation in amounts ranging from a few up to about 50%. Conduction in the surface moisture films appears to be electrolytic or ionic in character, with the proton-jump mechanism being the predominant mechanism for transfer of charge.[3]

Figure 4-2 illustrates the effect of temperature and humidity on particle resistivity. The influence of temperature on volume resistivity of a typical layer of collected particles is shown by the straight line in Figure 4-2 labeled "bone dry." In the presence of certain conditioning agents, the total resistivity becomes a function of the conditioning agent and temperature. This combined surface-volume conduction relationship is illustrated by the lower two curves in Figure 4-2 with water as the conditioning agent.

4.2.4.1.2 Conditioning methods: Control of particle resistivity by conditioning of the carrier gases plays an important role in electrical precipitation practice. Although the term conditioning usually implies the addition of chemicals or moisture to the flue gases, it is used here in a broader context and includes temperature and composition control.

Conditioning of gases by steam injection, water sprays, or wetting of raw materials to reduce particle resistivity is widespread, particularly where the natural moisture content of the gas is low and the temperature relatively high. Moisture also is favorable in raising the dielectric strength and reducing the viscosity of the gas. Conditioning by humidification is always more effective at low temperatures. At room temperature, for example, most dusts and fumes may be effectively conditioned by only 1% to 2% moisture in the gas, but 10% to 20% may be needed at 200°F to 300°F.[3]

Chemical conditioning agents may be effective in minute concentrations. A good example occurs in the fine cleaning of the exhaust gas in the powdered-catalyst petroleum-cracking process used widely in the production of high-octane gasoline. In the first full scale operation of this process, it was found that recovery of the valuable aluminum silicate catalyst dust in the electrical precipitator was hampered by high resistivity of the particles. Ammonia was found to be a highly effective chemical conditioner, and it was added to the precipitator gas in the proportion of only 1 part in 60,000 which was sufficient to drop the dust resistivity from 5×10^{11} to 10^{10} ohm-cm, and to raise precipitator efficiency from 96% to 99.8%.[3]

Moisture appears to be essential to the effectiveness of chemical conditioning agents. In general, the action of the conditioner increases with the amount of moisture in the gas and with decreasing temperature of the gas. Water vapor is therefore frequently referred to as a primary conditioning agent and chemicals are considered secondary conditioning agents. The effects of conditioning on particulate resistivity are shown in

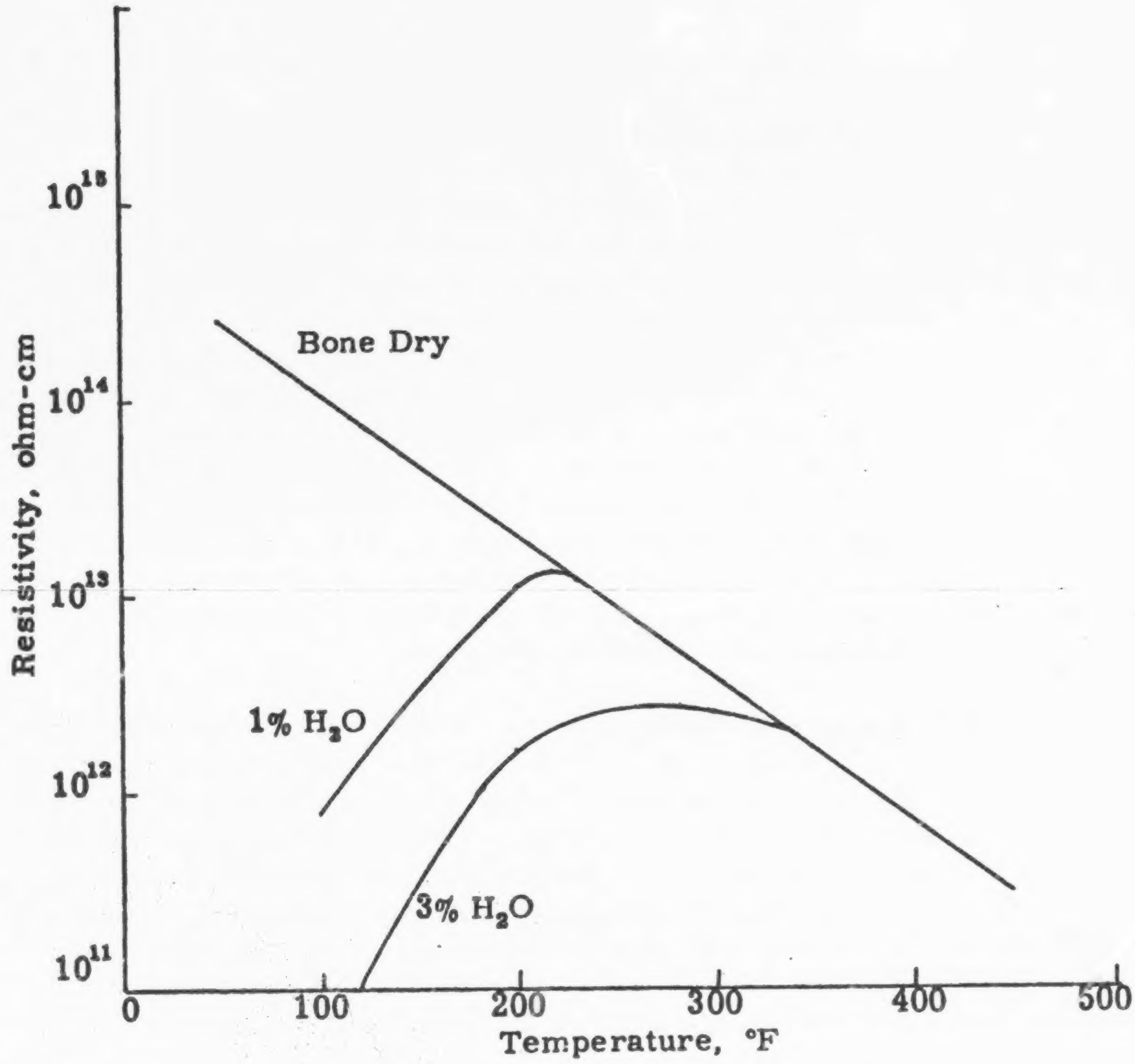

Figure 4-2 - Effect of Humidity on Particle Resistivity

Figures 4-3 and 4-4. The addition of a small amount of ammonia reduces the resistivity of a powdered catalyst by a factor of about 100, and the addition of diethylamine reduces resistivity by a factor of 10^3 to 10^6 (Figure 4-3). Figure 4-4 illustrates the effects of SO_3 conditioning on fly ash resistivity. Resistivity is plotted in terms of the percent of sulfuric acid fume added, with gas temperature as a parameter.3/

4.2.4.1.3 Resistivity measurement: Because of conduction modes and their dependence on operating conditions, particle resistivities measured directly in plant flues are preferable to those measured in the laboratory. Gaseous environments usually cannot be duplicated feasibly in the laboratory. In the in-situ measurements, the phenomenon of surface conduction usually predominates because of the presence of conditioners in the flue-gas stream. In the laboratory, these conditions are usually not present and conduction is by the volume mode. When in-situ measurements are compared to laboratory measurements, the in-situ resistivity is frequently 2 to 3 orders of magnitude lower. This discrepancy is most severe with fly ash. Laboratory measurements of fly ash resistivity have very little fundamental meaning, and the only meaningful measurements are those made in situ. Essentially all electrical resistivity data currently available in the literature have been determined under laboratory conditions. A more detailed discussion of particle resistivity is presented in References 2 and 3.

4.2.4.2 Electrostatic Attraction: Electrostatic attraction is also important in fabric filtration. Precipitation on the filter will result from electrostatic forces drawing particles and filter elements together when either or both possess a static charge. These forces may be either direct, when both particle and filter are charged, or induced, when only one is charged. Such charges are usually not present unless deliberately introduced during the manufacture of the fiber. Electrostatics assist filtration by providing an attraction between dust and fabric, and also affect particle agglomeration, fabric cleanability, and collection efficiency.

The type and quantity of charge acquired by a filter medium is a function of the filter type and the method of charging. The rate at which a fabric loses its charge is also an important consideration. This depends not only on the conductivity of the fibers but also on the humidity of the gases passing through the filter. Thus fabrics which are poor conductors retain a charge much longer than good conductors. In humid conditions a fabric acquires a surface film of moisture which also acts as a conductor.

Charges are induced in fabrics by friction, and the type and extent of charging that a particular material acquires relative to others can be measured by charging a series of materials in the same way. The usual technique consists of placing a strip of the material on an insulated ring and rubbing it with a strip of the reference fabric which is mounted on an

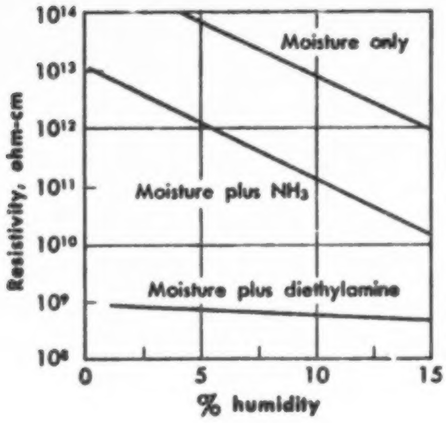

Figure 4-3 - Conditioning of a Weak Acidic Dust by Strong Bases. Catalyst clay dust from a powdered catalyst petroleum-cracking process, 310°F[3]

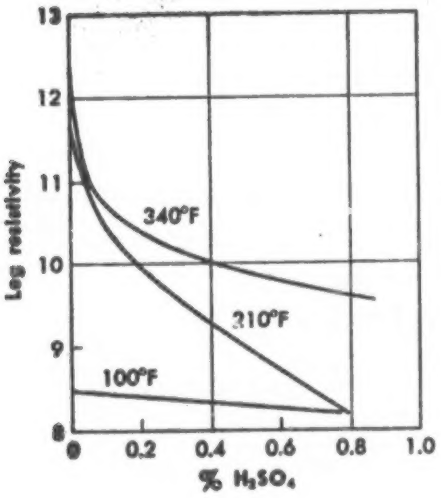

Figure 4-4 - Laboratory Conditioning Tests, Sulfuric Acid Fume with Fly Ash[3]

insulating rotating disc. The charge on the test strip is measured after a standarized number of turns of the charging disc, and again after a set period (frequently 2 min.) to find the rate of charge leakage. The maximum charge, measured immediately after charging, enables the materials to be placed in relation to one another in a triboelectric series (Table 4-1).[7,8]

Dust particles can be arranged into a similar series relative to one another and to filter fabrics. This arrangement can assist in the selection of filter fabrics with the most favorable charge characteristics for both particle collection and particle release, if the particles are to be removed by shaking, vibration or blowing.

Particles can be placed in one of three categories: Those which acquire a charge and do not agglomerate (Class I); those that acquire a charge and agglomerate (Class II), these being the active classes; and those which are not affected by the charge on the filter (Class III), being inactive. The active groups are divided into fine and coarse particles. Coarse particles do not present a problem in filtration as they are easily collected on the surface layers of the fabric, usually form a loose cake, and are easily shaken off. Fine particles are much more difficult to collect because they tend to penetrate the filter medium and often leak through. By selecting a highly charged filter medium, fine particles in Class II will be agglomerated, their collection improved, and they should form a loosely agglomerated cake on the fiber filter surface. If the filter has a high rate of charge loss under these conditions, cake release will also be assisted.[8]

Several dusts in the various categories have been experimentally investigated and their properties are listed in Table 4-2.[7,8]

4.2.5 Moisture Content

Moisture content influences both selection of control equipment and particle characteristics. Particle resistivity, flammability, and handling characteristics are strongly influenced by moisture content.

4.2.6 Toxicity

Toxicity charactertistics of particulates and carrier gases define important health aspects of particulate emissions. The toxicity aspects of the particulates might dictate the use of a control device where it would not otherwise be required.

TABLE 4-1

TRIBOELECTRIC SERIES FOR FABRICS[7]

	Electrostatic Units	
Positive		
	+ 25	
		Wool felt
	+ 20	
	+ 15	Glass filament, heat cleaned and silicone treated
		Glass spun, heat cleaned and silicone treated
		Wool, woven felt
	+ 10	Nylon 66, spun
		Nylon 66, spun, heat set
		Nylon 6, spun
		Cotton sateen
	+ 5	Orlon 81, filament
		Orlon 42, needled fabrics
		Arnel, filament
		Dacron, filament
		Dacron, filament, silicone treated
	0	Dacron, filament M.31
		Dacron, combination, filament and spun
		Creslan, spun: Azoton spun
		Verel, regular, spun: Orlon 81 spun (55,200)
		Dynel, spun
	- 5	Orlon 81 spun
		Orlon 42 spun
		Dacron, needled
	- 10	Dacron, spun: Orlon 81 spun (79475)
		Dacron, spun and heat set
		Polypropylene 01, filament
		Orlon 39B, spun
	- 15	Fibraryl, spun
		Darvan, needled
		Kodel
	- 20	Polyethylene B filament and spun
Negative		

Note: Polystyrene, Saran and Vinyon are at the far negative end of the series.

TABLE 4-2

RELATIONS OF FABRIC REQUIREMENTS TO DUST PROPERTIES AND DUST IN THE CATEGORIES LISTED[7]

Dust Classification	IA	IB	IIA	IIB	III
Relative particle size	Fine	Coarse	Fine	Coarse	Fine and coarse
Electrostatic properties	Active	Active	Active	Active	Inactive
Agglomerating tendencies	Little or none	Little or none	Positive	Positive	--
Criteria for filtration:					
Leakage	P_x	Const[a]	P_x to P_c^2	P_x to P_c^2	Fabric Construction dictates performance
High flow low Δp	Const[a]	P_m	P_x	P_x	
Criteria for cleaning:					
Leakage control	D_e	Const[a]	P_x to P_c^2	P_x to P_c^2	
Ease of cake removal	D_h	D_h	D_h	D_h	
Material	Calcined Calcium Silicate	Flux Calcined Diatomaceous Earth Commercial Finished Cement Ball Clay	Processed Natural Diatomaceous Earth Wheat Starch Taconite Zinc oxide Fume Nickel furnace fume Magnesite Cellulose Acetate Molybdic oxide Sugar	Carbon SRF	Kaolin

---

a/ Fabric construction determines property.

b/ Requires low density, rapidly agglomerating dust forming large aggregates.

P_x = maximum P.D. dust and fabric.
P_c = controlled P.D. dust and fabric.
P_m = mimimum P.D. dust and fabric.
D_h = high rate of charge dissipation.
D_e = low rate of charge dissipation.
[P.D. = Potential Difference]

4.2.7 Wettability and Solubility

These properties can affect dust separation in wet scrubbers, although they are generally only second-order effects. In general, wetting is the term applied to the phenomenon of a liquid adhering to a solid. Wettability depends upon the nature of the substance involved, and is related to boundary surface energies. In principle, wetting occurs when the adhesion energy between solid and liquid is greater than, or equal to, the cohesion energy of the liquid.

The determination of wettability is difficult in the case of morphologically heterogeneous dusts. Recent studies in Germany have indicated that a wettability trend can be expressed in terms of the velocity of rise of a liquid in capillaries of powders and the total time required for a liquid to rise a certain height.4/ Table 4-3 summarizes rates of rise and total wetting times for several dust samples using water as the liquid phase. The results indicate that the rates of rise and the wetting times differ greatly for individual dusts. Highest wettability is shown by dust from sludge of a wet scrubber operating in the cleaning room of a foundry. In contrast, the wetting properties of dust samples from the hot-blast cupola furnaces and the boiler soot are very poor.4/

Subsequent investigations, conducted with a test setup in which dust particles could be shot at individual droplets of water at different velocities, indicated that wettability did not markedly affect the efficiency of wet scrubbing. It was repeatedly shown that, regardless of particle type and velocity, a dust particle hitting the water droplet was always retained by the latter, even if the droplet was greatly deformed by the particle.4/ These results indicate, at least for the dust studied, that wetting behavior of particles in wet scrubbing is of secondary importance.

4.2.8 Flammability or Explosive Limits

These factors influence selection of control equipment and define handling hazards. Ignition and explosion behavior of dust is affected by electrostatic charging, chemical composition, the size and state of the solid surface, moisture content, and dust thermal properties. Carrier-gas temperature, pressure, and chemical composition also affect these limits.

4.2.9 Chemical Composition

Particulate and carrier-gas chemical composition exerts an influence on choice of control and auxiliary handling equipment. Composition also influences electrical properties, toxicity, reactivity, wettability, and most other particle properties.

TABLE 4-3

RATES OF RISE AND TOTAL WETTING TIMES MEASURED AT DIFFERENT DUST SAMPLES[4]

(Sample cross section: 0.50 cm^2, sample height: 0.5 cm, liquid: distilled water)

Origin of dust	Density (g/cm^3)	Rate of Rise $(cm/sec)\cdot 10^{-3}$	Total wetting time (sec.)
Boiler (largely soot)	2.57	$4.46\cdot 10^{-3}$	ca. 51,000
Hot-blast cupola furnace (basic)	2.44	$9.48\cdot 10^{-2}$	ca. 6,800
Hot-blast cupola furnace (acid)	2.68	0.226	1,153
Cold-blast cupola furnace	2.71	5.98	148
Swing grinding shop	3.17	25.72	63.6
Blast furnace	4.68	46.80	21.7
Boiler	2.30	96.32	12.6
Sand preparation (sludge)	2.51	192.58	6.14

4.2.10 Handling Characteristics

Particle handling and flow properties influence dust separation equipment and auxiliary devices for dust collectors. Powder flow properties result from a combination of a number of factors including transmission of external and body forces through the system, particle size and shape distribution, ruggedness and resilience of the particles, cohesion, adhesion of particles to surfaces, and adsorbed films especially of water.

Particle shaking properties are very important for the design of auxiliary devices for dust collectors and for the further treatment of separated dust. These properties include:

(1) Shakedown Weight - specific weight of highest packing density

(2) Angle of Repose - angle at which piled dust begins to slide

(3) Slide Angle - angle at which dust begins to slide on a base.

Shakedown weight exceeds the free bulk weight by a factor of 1.2 to 1.4; angle of repose lies between 25 degrees to 55 degrees and sliding angle between 35 degrees to 65 degrees. Both angles are influenced by particle size, moisture content of dust, particle shape, and cohesion and adhesion forces.

The abrasive behavior of dust characterizes its mechanical effect upon a surface with which it comes into contact. In gas cleaning, the inner walls of pipe conduits are subject to the highest abrasion. This dust property cannot be expressed by merely giving its hardness, since hardness expressed as resistance to the penetration of foreign bodies cannot be determined for dust particles. Furthermore, abrasive behavior is also affected by the shape and size of particles and their specific weight.

The corrosive characteristics of the particulates can influence the choice of gas-cleaning equipment, and, in many cases, dictate the materials of construction.

4.3 CARRIER-GAS CHARACTERISTICS

4.3.1 Volume Flowrate, Pressure, Temperature, and Composition

Control equipment choice and size are dictated by these parameters. The gas temperature also exerts an influence on particle resistivity, moisture content, and flammability limits. Pressure and composition affect flammability limits.

4.3.2 Corrosive Properties

Carrier-gas corrosive properties primarily influence selection of equipment construction materials.

4.3.3 Optical Properties

The optical properties of aerosols are of importance in connection with gas cleaning and air pollution, because the degree of pollution is commonly judged by visual appearance of stack discharge or of the atmosphere itself. Visual appearance is subjective and is associated with the observer, character of the sky, and physical character of the stack discharge.

Optical density is closely related to the visual appearance of the stack exhaust plume. The extinction coefficient is a function of the number of particles per unit volume, the particle size, shape, and size distribution.

4.3.4 Odor and Toxicity

Particulate and carrier-gas odor properties are secondary factors. Concentrations below toxic or harmful levels are primarily a problem from the standpoint of complaints from nearby residents. Malodorous gases and vapors include mercaptans, phenolic compounds, naphthenic acids, organic sulfides, nitrogen bases, aldehydes, and ammonia.

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CHAPTER 5

PRESENTATION OF EFFLUENT DATA FOR SPECIFIC INDUSTRIES

Effluent data for specific sources in the major industrial categories listed in Table 2-1, Chapter 2, are presented in tabular form in Chapters 6 - 24. Only numerical data are given in these tables. Table 5-1 is provided as a coding key for the tables of effluent characteristics in Chapters 6 - 24.

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TABLE 5-1

CODING KEY FOR TABLES OF EFFLUENT CHARACTERISTICS

I. General Note: All data for uncontrolled sources unless otherwise noted.

II. Specific Notes:

A. Particulates

1. Particle size;

   $x < y$, $x > y$.

   x = weight %, y = particle size (μ).

   Measuring technique noted. If no notation is listed, measuring technique was not reported or is unknown.

2. Solids loading: grains/scf, unless otherwise noted.

3. Chemical composition:

   solids - wt. % (unless otherwise noted).

4. Particle density: g/cm^3.

5. Electrical resistivity: ohm-cm, laboratory measurements unless otherwise noted.

6. Moisture content: wt %, unless otherwise noted.

7. Toxicity:

   a) N.T. - not toxic.

   b) numerical value - threshold limit, mg/m^3.

8. Solubility:

   s. - soluble.

   s. sl. - slightly soluble.

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TABLE 5-1 (Concluded)

d. - decomposes.

9. Wettability, hygroscopic, flammability, handling, optical, and odor characteristics: only a descriptive comment generally given; if numerical value is presented, units will be indicated.

B. Carrier Gas

1. Flow rate: flow-rate data presented in two forms:

   a) thousands of standard cubic feet per minute, M scfm, unless otherwise noted.

   b) thousands of standard cubic feet per ton of product processed, M/scf/ton, unless otherwise noted.

2. Temperature: °F.

3. Moisture content: vol %, unless otherwise noted. Dew point is in °F if listed under moisture content.

4. Chemical composition: vol %, unless otherwise indicated.

5. Toxicity:

   a) N.T. - not toxic.

   b) numerical value - threshold limit, mg/m^3.

6. Corrosivity, odor, flammability, and optical properties: only a descriptive comment generally given; if numerical value is presented, units will be indicated.

CHAPTER 6

STATIONARY COMBUSTION PROCESSES

6.1 INTRODUCTION

More than 29 million stationary combustion sources are currently in operation in the United States: (1) electric-utility power-generating plants, (2) industrial power plants and process heaters, and (3) space-heating units. Coal, oil, and gas are burned in a wide variety of equipment.[1]

Particulate emissions vary widely from unit to unit because processes, practices, and fuels all affect emission levels. For each fuel, several different processes are used for stationary combustion. Coal-fired electric generating plants utilize pulverized, cyclone, and stoker-fired boilers. Burners, combustion chambers, draft systems, heat transfer characteristics, and combustion controls of industrial units may vary widely. Steam, hot water, and warm air furnaces are in common use for domestic heating.

Stationary combustion sources are divided into electric utility, industrial, and commercial and residential groups for a more detailed discussion in the following sections.

6.2 ELECTRIC UTILITIES

The production of power by the combustion of coal, fuel oil, and gas contributes large quantities of particulates, sulfur oxides and nitrogen oxides to the atmosphere. Coal-fired units are the dominant source of particulate emissions. Particulate emissions from oil-fired power boilers are about 1% of emissions from similar coal-fired equipment. Use of natural gas as a fuel nearly eliminates particulate emissions. Since emissions depend so strongly on the type of fuel burned, discussion of emission rates, effluent characteristics, and control practices is presented for each fuel type in succeeding paragraphs.

6.2.1 Fuel Type

6.2.1.1 Coal-Fired: The modern coal-fired electric generating plant is comprised of a boiler, generator, condenser, coal handling equipment, dust collection and disposal equipment, water handling and treatment facilities, and heat recovery systems such as economizers and air heaters. Boilers in present-day usage include cyclone, pulverized, and stoker types with pulverized fuel boilers comprising nearly 90% of the total.

Pulverized fuel boilers utilize coal ground to a size such that about 70% passes 200 mesh. The coal and preheated combustion air are direct-fired into the boiler as determined by the steam requirements. The coal-air ratio is automatically regulated to give optimum combustion for all load conditions. Boilers are classified as horizontal, vertical, or tangential, depending upon the firing position of the burners.[2/]

Pulverized coal-fired boilers are also classified as either wet bottom or dry bottom, depending on the operating temperature and ash-fusion temperature. In wet-bottom boilers, the temperature is maintained above the ash-fusion temperature so the slag is molten and can be removed from the bottom as a liquid. Dry-bottom boilers operate at temperatures below the ash-fusion point, and the ash is removed in a solid state.[2/]

Cyclone boilers operate with much coarser coal, typically 95% minus 4 mesh. The heater is a water cooler cylinder with combustion air introduced tangentially. Combustion occurs at temperatures sufficiently high to melt a high percentage of the ash which is discharged through slag tap openings.

Less than 5% of the coal consumed in electric-generating plants is burned in stoker boilers. A variety of stoker units exist, but spreader-stoker units have the highest steam output rates.[3/] The spreader-stoker unit combines suspension and fuel-bed firing; the stoker mechanism feeds from the hopper onto a rotating flipper mechanism, which in turn throws the fuel into the furnace. Because the fuel is burned partly in suspension and partly on the grate, the fuel bed is thin, and response to fluctuations in load is rapid. The grates are either stationary or continuous moving from the rear to the front. Vibrating, oscillating, traveling, and chain grates are used for moving the fuel toward the ash-receiving pit.[3/] Fly-ash reinjection is also practiced in many plants.

6.2.1.2 Oil-Fired: Compared to coal-fired units, oil-fired electric-generating plants emit a minor amount of particulate matter to the atmosphere. The rates of emissions from these units are affected by variable operating conditions and by the nature of the fuel used.

Two different basic designs of furnace are used in oil-fired plants: tangentially and horizontally fired. The tangentially fired unit is built so that the flame is propagated in a cylindrical form. The unit is constructed to produce a spiral upward motion of the flame and combustion products around the walls of the cylindrical firebox. The tangentially fired unit is a relatively new and infrequently used design.[4/]

Horizontally fired units are usually fired at right angles to the walls of the firebox, but may be fired at various angles. They may be fired on one or more sides, or from the bottom of the firebox. The firebox may be square, rectangular, or cylindrical. Horizontal firing tends to concentrate the hot gases in the center of the firebox.

6.2.1.3 Gas-Fired: Natural gas is also utilized in power plants. Particulates and oxides of sulfur emissions are insignificant compared with those of other fossil fuels. Control equipment has not been required for natural gas combustion equipment.

6.2.2 Emission Rates

6.2.2.1 Coal-Fired: The emission rate of particulate matter from a coal-fired furnace is related to many factors, mainly gas velocity, particle size, particle density, fuel-burning rate, combustion efficiency, flue gas temperature, furnace configuration, coal composition and size, and the initial state of the raw coal.

The following variables are thought to be the most important in relation to particulate emissions:3/

1. Amount of ash in the coal;

2. Method of burning the coal;

3. Rate at which the coal is burned.

For any specific furnace, coal-ash content is the dominant variable. Other conditions remaining fixed, the fly-ash emission will be approximately proportional to the ash content of the coal. The heating value of the coal is related to its ash content. Figure 6-1 presents a nomograph for estimating particulate emissions from coal combustion.3/

The method of burning the coal influences particulate emission rates. When coal is thrown or blown into a furnace, combustion takes place in suspension. As the pieces of coal burn, they get smaller, and thus their chance of being exhausted with stack gases is increased. When coal is pushed or pulled into a furnace to form a bed, the coal or ash has less chance of being entrained by the flue gases because of impingement onto larger particles. When coal is introduced tangentially into a cylinder, such as in the cyclone furnace, the burner acts as a cyclone separator and thus reduces emission of larger particles.3/

As the velocity of the gases passing through the furnace increases, larger particles of coal and ash are carried out of the furnace. The velocity

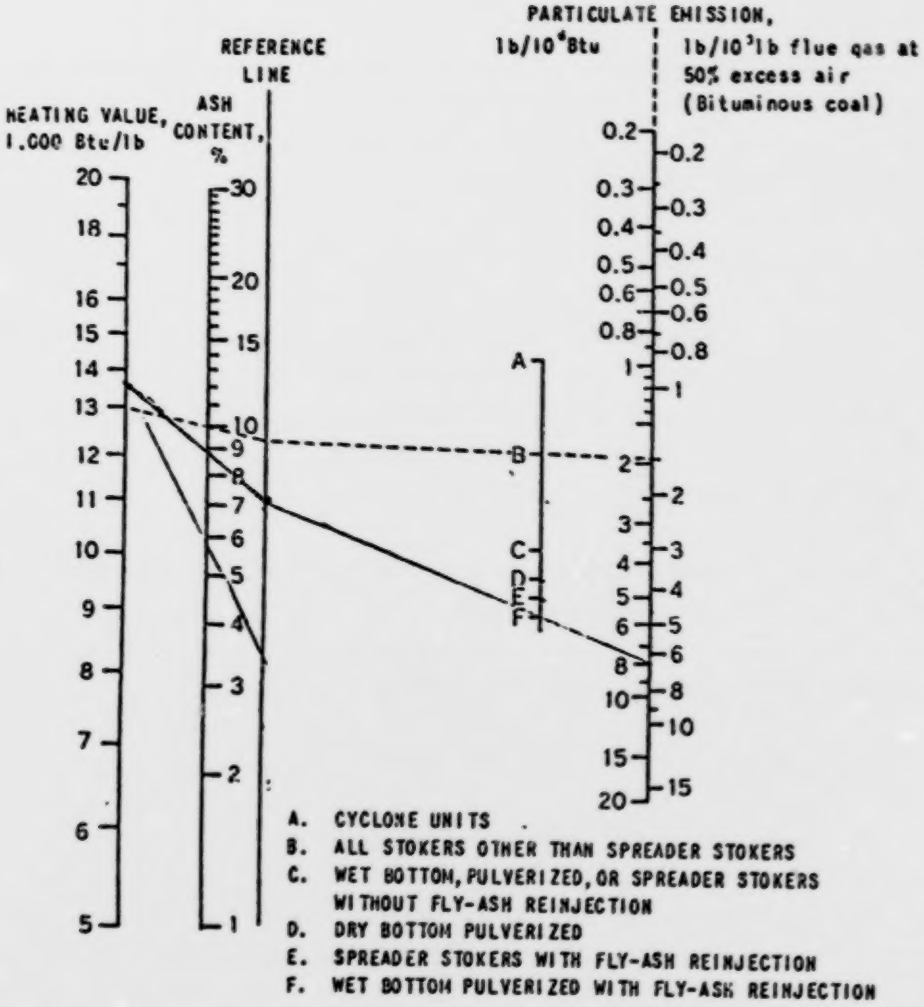

Figure 6-1 - Nomograph for Estimating Particulate Emissions From Coal Combustion (Without Air Pollution Control Equipment)[3]

of the gases is directly proportional to the firing rate of a given furnace; thus, the size of the particle and rate of emission should be a function of the firing rate. In a similar manner, the excess air, pressure, and temperature are related to the particulate emissions in that they control the gas velocity.[3]

Emission rates for the various types of coal-burning units are summarized in Table 6-1. As would be expected, over 90% of the emissions are from pulverized coal-fired boilers. The influence of firing method is clearly shown, as the emission factor for cyclone units is 20 to 25% of that for pulverized and stoker units.

6.2.2.2 Oil-Fired: The particulate loading of stack gases depends primarily upon the efficiency of combustion and the rate of build-up of boiler deposits. Poor mixing, low flame temperatures, and short residence time in the combustion zone cause larger particles, higher combustible content, and higher particulate loadings.[4] The degree of atomization has an important effect on particulate emissions. Low-pressure atomization produces larger fly-ash particles and a higher particulate loading.[4] High-pressure atomization (400 psig or greater) produces smaller particles, fewer cenospheres, and lower particulate loadings.[4]

The soot-blowing operation markedly increases the particulate loading in the stack gases. An increase of 1.7 to 3.3 times the normal emission level has been reported during soot blowing.[4]

Emission rates for oil-fired units are summarized in Table 6-1. Particulate emissions are estimated at 36,000 tons/year.

6.2.2.3 Gas-Fired: Meager data exist on particulate emissions from gas-fired units. Table 6-1 summarizes available information. Particulate emissions are estimated to be 24,000 tons/year.

6.2.3 Characteristics of Effluents from Electric Generating Plants

6.2.3.1 Coal-Fired: The chemical and physical characteristics of effluents from coal-fired electric generating plants are summarized in Table 6-2. Particulates from pulverized coal furnaces are larger in size than those from cyclone furnaces. There is also a rather large variation in particle size for each furnace. Furnace design, operating conditions and coal composition undoubtedly influence the size of emitted particulates. Outlet grain loadings from pulverized furnaces generally exceed those from cyclone furnaces.

TABLE 6-1

PARTICULATE EMISSIONS
FUEL COMBUSTION IN STATIONARY SOURCES

Source	Amount of Fuel Burned	Emission Factor	Efficiency of Control (C_c)	Application of Control (C_t)	Net Control ($C_c \cdot C_t$)	Emissions (tons/yr)
I. Coal						
A. Electric Utility						
1. Pulverized	258,400,000 tons	16 A*	0.92	0.97	0.89	2,710,000
2. Stoker	9,900,000	13 A	0.80	0.87	0.70	217,000
3. Cyclone	28,700,000	3 A	0.91	0.71	0.64	182,000
				Total from electric utilities		3,109,000
B. Industrial						
1. Pulverized	20,000,000	16 A	0.85	0.95	0.81	322,000
2. Stoker	70,000,000	13 A	0.85	0.62	0.52	2,234,000
3. Cyclone	10,000,000	3 A	0.82	0.91	0.75	39,000
				Total from industrial units		2,595,000
C. Residential and Commerical	20,000,000	5 A				300,000
				Total from coal		6,004,000
II. Fuel Oil						
A. Electric Utilities	7,180,000,000 gal.	10 lb/1,000 gal.				36,000
B. Industrial						
1. Residual	7,510,000,000 gal.	23 lb/1,000 gal.	--	--	--	87,000
2. Distillate	2,360,000,000 gal.	15 lb/1,000 gal.	--	--	--	18,000
C. Residential and Commercial	36,530,000,000 gal.	8 lb/1,000 gal.				146,000
				Total from fuel oil		287,000
III. Natural Gas and LPG						
A. Electric utilities	3,143,143,000 mil. cu. ft.	15 lb/mil cu ft	--	--	--	24,000
B. Industrial	9,270,000 mil. cu. ft.	18 lb/mil cu ft	--	--	--	84,000
C. Residential and Commercial	6,250,000 mil. cu. ft.	19 lb/mil cu ft	--	--	--	59,000
				Total from natural gas		167,000
	Total for fuel combustion, stationary sources					6,458,000

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* A is percent ash.

TABLE 6-2

EFFLUENT CHARACTERISTICS
STATIONARY COMBUSTION PROCESSES‡

A. Particulate (Part I)

Source	Particle Size	Solids Loading	Chemical Composition	Particle Density	Electrical Resistivity	Moisture Content	Toxicity
Electric Generating Plants							
I. Coal Fired Type of boiler							
a. Pulverized	25 < 10, 49 < 20, 79 < 44						
1. Vertical*		4.7-4.8**	Typical Fly Ash: SiO_2: 17-64 avg. 43, Fe_2O_3: 2-36 avg. 15, Al_2O_3: 9-58 avg. 24, CaO: 0.1-22 avg. 4, MgO: 0.1-5 avg. 1.0, Na_2O: 0.3-4 avg. 0.9 Ignition Loss 0.4-36 avg. 8.3 Small Amounts TiO_2, K_2O, FeO, P_2O_5, SO_3 Polynuclear hydrocarbons (see Table 6-3 for detailed data)	Bulk Density 30-50 lb/ft^3 Particle Density 0.6-3.0, avg. 2.3 Particle shape varies widely. May be minute spheres, slivers, or spongy, lace-like entities.	Varies from 10^8-10^{13}	0.23 (avg. 30 samples)	N.T., but acidic
2. Corner*		2.9-3.7; avg. 3.3					
3. Front wall horizontal*		2.4-2.5					
4. Horizontally opposed		2.9-4.9; avg. 3.9					
5. Unspecified	BAHCO Analysis 90% CF 69 Measurements in following range 6-20 < 3, 12-32 < 5, 28-56 < 10, 42-79 < 20, 61-93 < 40 Most Probable Distribution 15 < 3, 25 < 5, 42 < 10, 65 < 20, 81 < 40	1.02-5.6 Mean: 3.3					
b. Cyclone*	72 < 10, 87 < 20, 95 < 44 BAHCO Analysis 20-72 < 5, avg. 40 < 5; 40-96 < 10, avg. 65 < 10; 70-99 < 20, avg. 81 < 20, 81-100 < 40, avg. 92 < 40	0.2-3.2 Mean: 0.85					
c. Stoker							
1. Spreader stoker*	11 < 10, 23 < 20, 42 < 44	1.5-2.3; avg. 1.9					
2. Underfeed stoker	7 < 10, 15 < 20, 30 < 44	0.05-0.2					
d. Unspecified boiler type	Coulter Counter 2-79 < 10, avg. 18 < 10; 4-89 < 20, avg. 35 < 20; 20-98 < 44, avg. 59 < 44 Optical and Electron Microscope 42-68 < 10, avg. 58 < 10; 60-87 < 20, avg. 79 < 20; 86-99 < 44; avg. 93.5 < 44 Iterative Sedimentation 45-69 < 10, avg. 59 < 10; 64-85 < 20, avg. 76 < 20; 70-91 < 44; avg. 84 < 44 BACHO Analysis 12-26 < 10, avg. 16.6 < 10; 20-36 < 20, avg. 26 < 20; 42-95 < 44, avg. 63.3 < 44						

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‡ See Coding Key, Table 5-1, Chapter 5, p. 45, for units for individual effluent properties.
* Partial and full load tests (partial load ~ 75% load); 30-50 excess air.
**Corrected to 12% CO_2, dry basis.

TABLE 6-2 (Continued)

A. Particulate (Part I, Concluded)

Source	Particle Size	Solids Loading	Chemical Composition	Particle Density	Electrical Resistivity	Moisture Content	Toxicity
Electric Generating Plants (Concluded)							
II. Oil Fired							
a. Typical operation	90 < 1	0.013-0.2, avg. 0.05, most common value - 0.03-0.035	Fly Ash: See Table 6-4 for detailed data	2.5 Particle shape varies, many small spheres			N.T., but acidic
b. Soot Blowing		0.13-0.19					
Industrial Furnaces		0.01-0.265, avg. 0.083					

A. Particulate (Part II)

Source	Solubility	Wettability	Hygroscopic Characteristics	Flammability or Explosive Limits	Handling Characteristics	Optical Properties
Electric Generating Plants						
I. Coal-Fired	Contains H_2O soluble components	Difficult to wet			Difficult to handle, aggomerates Internal Friction Angle 420-590 μ - 25.1° 295-420 μ - 25° 250-295 μ - 20.3° 149-250 μ - 18.1-24.2° 105-149 μ - 16.3-23.3° 74-105 μ - 14.2-22° 44- 74 μ - 9.3-18.7° 0- 44 μ - 1.1° External Friction Angle (with aluminum) 420-590 μ - 16.7° 295-420 μ - 22° 250-295 μ - 19.5° 149-250 μ - 13.28.4° 105-149 μ - 20.5-24° 74-105 μ - 14.6-27.3° 44- 74 μ - 12-16.6° 0- 44 μ - 14.4-15.3° Cohesion 420-590 μ - 13.5 g/in^2 295-420 μ - 0.5 250-295 μ - 5.4 149-250 μ - 8.5-20.5 105-149 μ - 13.5 74-105 μ - 0.5-5.0 44- 74 μ - 6.0-14.5 0- 44 μ - 14.5-21	Color varies from light tan or grey to various shades of black
II. Oil-Fired	30-60% soluble solids	Difficult to wet				

TABLE 6-2 (Continued)

B. Carrier Gas

Source	Flow Rate	Temperature	Moisture Content	Chemical Composition	Toxicity	Corrosivity	Odor	Flammability or Explosive Limits
Electric Generating Plant								
I. Coal Fired Type of Boiler a. Pulverized								
1. Vertical*	(a) 297-397 avg. 350 (b) 362-434 avg. 400	245-258 avg. - 252	6.4	CO_2 - 12.5-12.6 O_2 - 6.2-6.6 N_2 - balance CO - 13-17 ppm NO_x - 161-221 ppm SO_2 - 1,450-1,700 ppm SO_3 - 46-66 ppm	SO_2 - 5 irritant CO - 100			
2. Corner*	(a) 284-362 avg. 323 (b) 387-417 avg. 402	253-283 avg. - 268	7.0-8.0	CO_2 - 14.4-14.9 O_2 - 4.2-4.7 N_2 - balance CO - 11-39 ppm NO_x - 393-526 ppm SO_2 - 1,120-1,150 ppm SO_3 - 8-10 ppm				
3. Front wall* horizontal	(a) 254-329 avg. 292 (b) 378-394 avg. 386	244-257 avg. - 251	5.9	CO_2 - 13.3-13.6 O_2 - 5.3-5.6 N_2 - balance CO - 5-12 ppm NO_x - 413-500 ppm SO_2 - 1,080-2,120 ppm SO_3 - 3-11 ppm				
4. Horizontally* opposed	(a) 44-62 avg. 53 (b) 392-399 avg. 396	314-315 avg. - 314.5	6.6-6.8 avg. 6.7	CO_2 - 12.8-13.2 O_2 - 5.9-6.0 N_2 - balance CO - 44-69 ppm NO_x - 393-395 ppm SO_2 - 1,560-1,730 ppm SO_3 - 8-10 ppm				
b. Cyclone*	(a) 444-558 avg. 501 (b) 519-643 avg. 581	265-279 avg. - 272	6.3-6.6 avg. 6.45	CO_2 - 12.0-12.8 O_2 - 6.4-6.8 N_2 - balance CO - no data NO_x - 742-1,204 ppm SO_2 - 1,350-1,380 ppm SO_3 - 13-21 ppm				
c. Spreader stoker*	(a) 44-54 avg. 49 (b) 351-383 avg. 367	396-426 avg. - 411	7.4-7.8 avg. 7.6	CO_2 - 12.1 O_2 - 6.6-6.9 N_2 - balance CO - 13-29 ppm NO_x - 430 ppm SO_2 - 1,280-1,380 ppm SO_3 - 52-58 ppm				
II. Oil Fired a. Horizontally fired	(a) 47-12,400 (b) 348-780 avg. 440	200-688 avg. - 315	6.6-9.8 avg. - 8.4	CO_2 - 5.9-15.4 avg. - 11.7 O_2 - 0.7-13.2 avg. - 4.2 N_2 - balance SO_2 - 118-2,200 ppm avg. - 957 ppm SO_3 - 2-75 ppm avg. - 19.5 ppm (most common value 14-22 ppm) NO_x - 15-900 ppm avg. - 414 ppm (most common value 460-480 ppm)				
b. Tangential	(a) 206-216 (b) 384-396 avg. 390	270		CO_2 - 11.1-18.2 avg. - 14.7 O_2 - 2.2-6.8 avg. - 4.3 NO_x - 160-400 ppm avg. - 260 ppm Most common value, 180-260 ppm				

TABLE 6-2 (Concluded)

B. Carrier Gas (Concluded)

Source	Flow Rate	Temperature	Moisture Content	Chemical Composition	Toxicity	Corrosivity	Odor	Flammability or Explosive Limits
Industrial Furnace								
1. Pressure atomizing	(a) 0.3-1.2 (b) 0.3-1.1 avg. 0.6	250-370 avg. - 310	3.0-9.8 avg. - 6.0	CO_2 - 3.9-12.4 avg. - 6.6 O_2 - 4.5-16.3 avg. - 11.0 CO - 0.002 - 0.01 avg. - 0.002 SO_2 - 98-355 ppm avg. - 214 ppm SO_3 - 1.4-3.2 ppm avg. - 2.3 ppm NO_x - 34-128 ppm avg. - 60 ppm				
2. Steam atomizing	(a) 1.7-10 (b) 0.3-0.6 avg. 0.44	320-710 avg. - 548	6.3-12.7 avg. - 9.4	CO_2 - 4-8.2 avg. - 6.4 O_2 - 7.8-14.0 avg. - 10.1 CO - 0.001-0.003 avg. - 0.001 SO_2 - 7-700 ppm avg. - 366 ppm SO_3 - 1.2-6.7 ppm avg. - 4.2 ppm NO_x - 15-368 ppm avg. - 229 ppm				
3. Centrifugal atomizing	(a) 1.2-4.0 (b) 0.39-0.8 avg. 0.63	240-500 avg. - 373	4.4-8.2 avg. - 6.3	CO_2 - 2.7-6.3 avg. - 4.7 O_2 - 9.8-16.2 avg. - 12.7 CO - 0.001-0.02 avg. - 0.008 SO_2 - 11-102 ppm avg. - 40 ppm SO_3 - 0.5-5.6 ppm avg. - 2.6 ppm NO_x - 20-72 ppm avg. - 37 ppm				

TABLE 6-3

POLYNUCLEAR HYDROCARBON CONCENTRATIONS[5]
(Micrograms/10^6 Btu Heat Input)[a]

	Type of Boiler Firing					
	Pulverized					
Compound	Vertical	Corner	Front-Wall	Horizontally Opposed	Spreader Stoker	Cyclone
Fluoranthene	200	300	80	188	50	79
Pyrene	155	140	180	91	105	1,025
Benzo(a)pyrene	19	140	19	81	< 20	223
Benzo(e)pyrene		86	23	265	30	395
Benzo(ghi)perylene		150	7	645		198
Coronene		7		56	5	6
Perylene		71				17

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[a] After fly-ash collector during full-load operation. Average values for two tests at each unit. A blank indicates that the compound was not detected.

TABLE 6-4

ELEMENTAL ANALYSES OF TOTAL PARTICULATES[4]

(Data in Percent)

Elements	Test A Total solids from burning PS[a]/400 oil (collected in a laboratory electrical precipitator at 230°F)	Test B Total solids from burning 4° API oil (collected in a glass filter sock at 300°F)
Carbon	58.1[b]	18.1[b]
Ether, soluble	2.3	4.4
Hydrogen	-	-
Ash (900°C)	17.4	51.2
Sulfates as SO_3 (incl. H_2SO_4)	17.5	25.0
Chlorides as Cl	-	0.5
Nitrogen as NO_3	-	0.3
Iron as Fe_2O_3	3.1	3.7
Chromium as CrO_2	0.06	0.3
Nickel as NiO	1.8	13.2
Vanadium as V_2O_3	2.5	4.7
Cobalt as Co_2O_3	0.08	0.3
Silicon as SiO_2	0.6	9.7
Aluminum as Al_2O_3	1.6	14.9
Barium as BaO	0.4	0.1
Magnesium as MgO	0.2	0.7
Lead as PbO	0.1	0.2
Calcium as CaO	0.2	0.4
Sodium as Na_2O	0.9	3.0
Copper as CuO	0.01	0.25
Titanium as TiO_2	-	0.004
Molybdenum as MoO_2	0.02	0.03
Boron as B_2O_3	0.01	0.1
Manganese as MnO_2	0.04	0.04
Zinc as ZnO	-	0.06
Phosphorus as P_2O_5	0.9	-
Strontium as SrO	0.04	-
Titanium as TiO	0.03	-

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a/ Pacific Standard.

b/ Value probably includes minor amount of hydrogen.

Fly ash (particulate emitted from combustion process) is a heterogeneous material and is composed of a variety of shapes. Cenospheres, unburned carbon particles, and mineral matter are the principal components. Percentages of these constituents vary from sample to sample, depending upon factors such as coal composition and furnace operation.

6.2.3.2 Oil-Fired: Table 6-2 presents data on the effluent characteristics of oil-fired electric-generating plants. Limited data were found on particle size distributions for particulate emissions from oil-fired units. The predominant size (over 90%) is less than $1\,\mu$. Size distribution will depend upon the degree of atomization of the oil, the efficiency of mixing, the number of collisions between fly-ash particles, the flame temperature, the design of the firebox, and the flue-gas path through the boiler to the stack. The lighter particles usually contain less carbon and are smaller in size.

The larger particles are skeletons of burned-out fuel particles, called cenospheres, which are hollow, black, coke-like spherical particles.[4] The smaller particles formed by the condensation of vapors are of regular shape and usually have a maximum dimension of about $0.01\,\mu$.[4] Fuel atomization usually reduces the number of cenospheres.

6.2.3.3 Gas-Fired: No detailed data were found on emissions from gas-fired units. Particulates can be assumed to be less than $5\,\mu$ in size, and gaseous emissions will contain O_2, N_2, CO_2, SO_2 and NO_x.

6.2.4 Control Practices and Equipment for Electric-Generating Plants

6.2.4.1 Coal-Fired: The dust collectors used for coal-fired power plants are shown in Table 6-5 with their usual expected efficiency in Table 6-6.[3] Optimum expected performance of various types of cleaning systems is shown in Table 6-7[1].

A comparison of the cost of various types and combinations of control equipment is given in Table 6-8.[6]

The problem of particulate matter is not solved with its collection. The costly matter of disposal still remains. This cost ranges from \$0.50 to \$2.00/ton for most utilities. The average is about \$0.74/ton.[1]

6.2.4.1.1 Electrical precipitators: Electrical precipitators are used extensively in power plants. A recent survey shows that in recent years high-efficiency electrostatic precipitators are being installed almost exclusively.[7] Recent trends toward the use of low-sulfur coal may require increasing the capacity of the electrostatic precipitators. A reduction in the sulfur content of the coal is apt to increase fly-ash resistivity, thereby reducing the efficiency of existing electrostatic precipitators.[6]

TABLE 6-5

DUST COLLECTORS FOR COAL-FIRED HEATING AND POWER PLANTS[3]

Collector Type	Collecting Action	Recommended Application	Efficiency Relative to Particle Size	Draft Loss, Inches of Water	Other Considerations
Cinder trap	Gravity	Smaller plants with underfeed, vibrating, chain, and traveling-grate stokers	30 to 40% for 45 μ and smaller; 75% or more for particles over 45 μ	0.1 to 0.5 (natural draft usually sufficient)	Used mainly to eliminate cinder nuisance in immediate plant area.
Medium draft loss cyclone	Inertia	Smaller plants with very critical on-grate firing	Overall--to 65%, 100% over 25-μ size	0.4 to 1.5	Abrasion may occur: made in variety of designs to fit job.
Single cyclone (large diameter)	Centrifugal force and inertia	On-grate firing at high rates and some spreader stokers	50 to 90% for particles over 20 μ	0.5 to 2.0	Made in variety of designs. Care required to fit design to job.
Multicyclone (small diameter tubes)	Centrifugal force and inertia	Spreader stoker	75 to 90% for particles over 10 μ	2.0 to 6.0	Abrasion may be a problem.
Wet scrubber	Inertia	Spreader stoker and pulverized-coal-firing units	70 to 90%, depending on particle size; 75% over 2 μ	13 to 20	Caking and corrosion may be a problem, also water recovery.
Electrostatic precipitator	Electrical attraction	Pulverized-coal-firing unit	85 to 99% - < 1 to 10 μ	0.1 to 0.5	Performance affected by resistivity of particles
Siliconized glass filter	Filtering	Pulverized-coal-firing units	98 to 99% for < 1 to 44 μ	1 to 6	Exit temperature limited to 600°F.

TABLE 6-6

USUAL EXPECTED EFFICIENCY RANGES FOR COMMONLY USED CONTROL EQUIPMENT[3]

(Percent)

Type of Firing or Furnace	Type of Control Equipment			
	Electrostatic Precipitator	High-Efficiency Cyclone	Low-Resistance Cyclone	Settling Chamber, Expanded Chimney Bases
Cyclone	65-99	30-40	20-30	-
Pulverized	80-99.9	65-75	40-60	-
Spreader stoker	-	85-90	70-80	20-30
Other stokers	-	90-95	75-85	25-50

TABLE 6-7

OPTIMUM EXPECTED PERFORMANCE OF VARIOUS TYPES OF GAS CLEANING SYSTEMS FOR STATIONARY COMBUSTION SOURCES[4]

	Removal of Uncontrolled Particulate Emissions (percent)						
	Systems in Operation					Systems Under Development	
Sources	Settling Chambers	Large Diameter Cyclones	Small Diameter Cyclones	Electrostatic Precipitators	Stack Sprays	8-In. Pressure Drop Scrubbers	Fabric Filters
Coal-fired							
Spreader, chain grate, and vibrating stokers	50	60	85	99.5	60	99+	99.5
Other stokers	60	65	90	99.5	80	99+	99.5
Cyclone furnaces	10	15	70	99.5	b/	b/	b/
Other pulverized coal units	20	30	80	99.5	b/	99+	99.5
Oil-fired	5[a]	10[a]	30[a]	75.0[c]	b/	b/	b/

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a/ Efficiency estimated--not commonly used.
b/ Insufficient data for estimate.
c/ Designed for 99% efficiency when firing with coal.

TABLE 6-8[6]

AIR CLEANING EQUIPMENT INSTALLED COST BASED ON 1,000 MW UNIT (1968)

Furnish, Deliver, Erect
(Supports and Flues not Included)

	Mechanical (cyclone) (75%)	Electro-static Precip. (95%)	Electro-static Precip. (99%)	Comb. Mech-Electro. (95%)	Comb. Mech-Electro. (99%)	Comb. Electro-Mech. (99%)	Bag Filter
$/MW at 300°F	$ 730	$ 3,330	$ 5,200	$ 3,830	$ 4,470	$ 6,160	$ 7,650
$/lb steam/hr at 300°F	0.11	0.48	0.76	0.56	0.69	0.90	1.12
$/ton coal/hr at 300°F	2,300	10,400	16,200	12,000	14,800	19,300	23,800
$/CFM flue gas at 300°F	0.25	1.00	1.50	1.15	1.40	1.80	2.25
$/CFM flue gas at 700°F	0.20	0.85	1.35	1.00	1.15	1.55	

For a 500-800 megawatt plant, an electrostatic precipitator with a design efficiency of 95%, treating 300°F flue gases and handling fly ash (which is relatively easy to collect) could be installed for a cost between $800 and $1,200/megawatt generating capacity. An electrostatic precipitator of 99% efficiency could be expected to cost between $1,400 and $2,200/megawatt of generating capacity.6/

Additional cost data, on the basis of volume flow rate, are given in Figures 6-2 and 6-3, and Table 6-9.2/ Data for fly ash disposal costs are given in Figures 6-4 and 6-5.

The relationship between the collecting area required in an electrostatic precipitator and the collection efficiency for coals of different sulfur content is shown in Figure 6-6.9/

6.2.4.1.2 Fabric filters: The principal objections to baghouse operation, that is, encrustation, blinding and deterioration of the cloth, can be overcome by injecting dry dolomite dust into the gas stream and ahead of the collection devices. Sulfur oxides react in the gas stream and on the surface of the bags to form calcium sulfate, a collectable solid. Bag filter installations are being tested with hopes of future application.10/

One prototype unit has been tested on an oil-fired boiler in California. This unit handles 820,000 cfm at 258°F, using a gas (ft^3/min) to cloth (ft^2) ratio of 6.5:1 along with an alkaline additive. This unit achieves high particulate and sulfur-trioxide collection efficiencies although a number of design and operating problems have been encountered.11/

The cost of a baghouse installation, including the additive handling system, has been estimated at $2.25/scfm.12/

6.2.4.1.3 Cyclones: Multiple small-diameter cyclones are used on mechanical draft conbustion units either as precleaners for electrostatic precipitators or as final cleaners. Efficiencies of well-designed units range from 90% for some stoker-fired units to 60% for coal-fired cyclone furnaces.

The efficiency of the cyclone or multicyclone collectors depends on size, shape, and density of the particles as well as other factors. It diminishes drastically in the range of 5 to 10 μ in size. The effect of particle size on collection efficiency at different pressure drops (inches of H_2O) is shown in Figure 6-7.13/

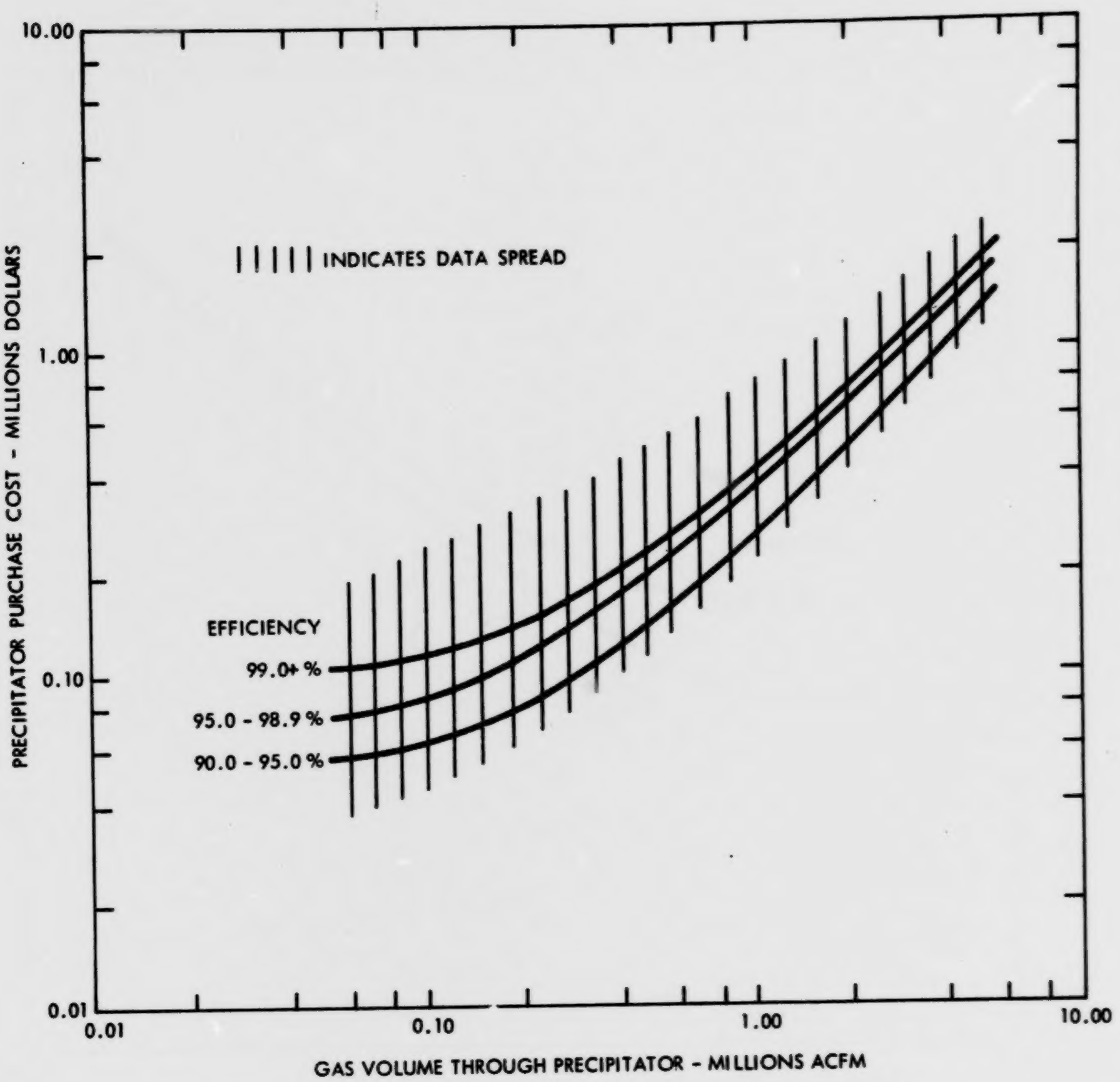

Figure 6-2 - Precipitator Purchase Cost (FOB) as a Function of Gas Volume Treated (Period 1965 - 1969)2/

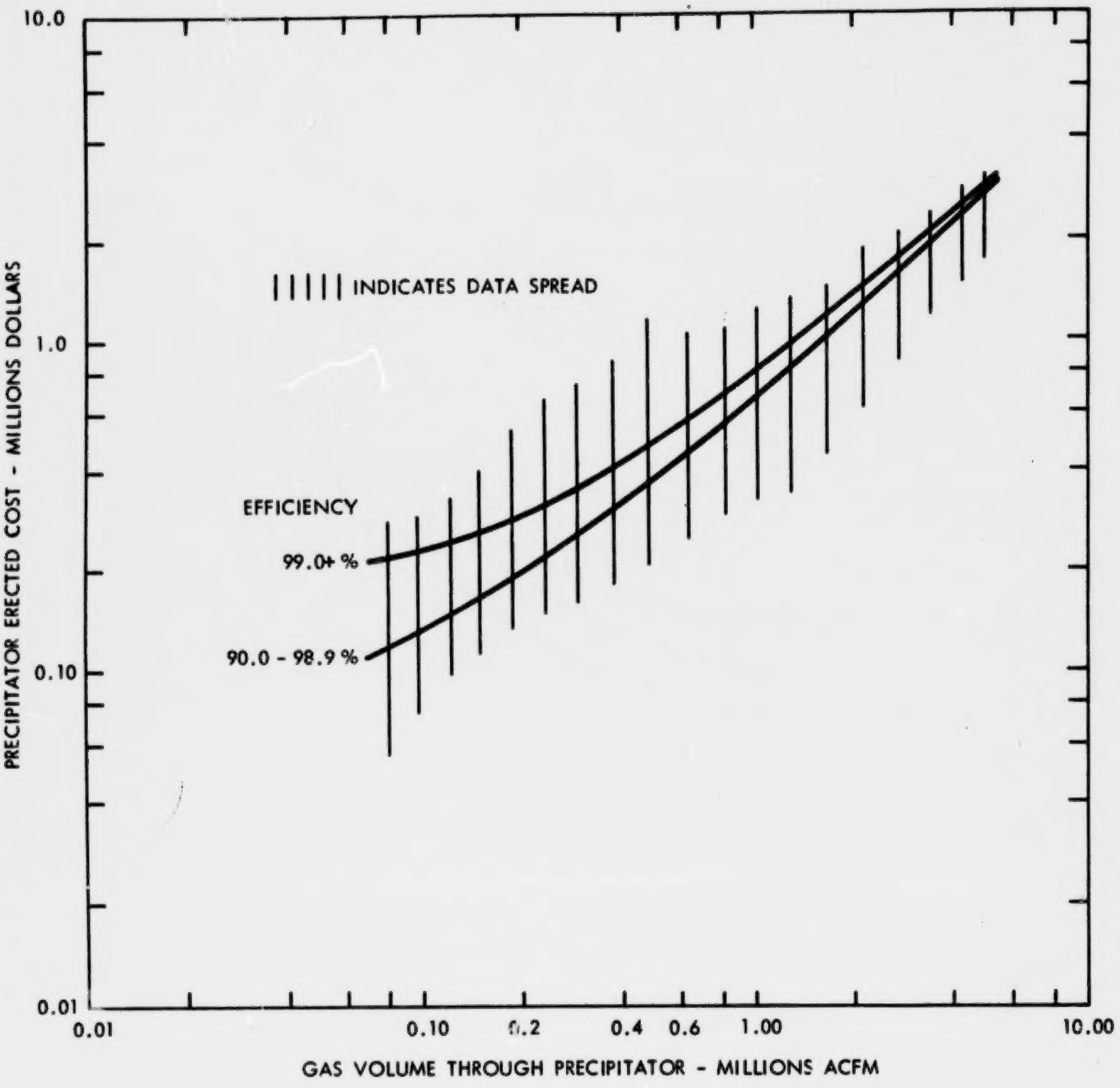

Figure 6-3 - Precipitator Erected Cost as a Function of Gas Volume Treated (Period 1965 - 1969)2/

TABLE 6-9

PRECIPITATOR COSTS (1965 - 1969)[2]

Efficiency	Gas Volume Range - Millions ACFM							
	0-0.249		0.250-0.499		0.500-0.999		> 1.00	
Range (%)	FOB	Erected	FOB	Erected	FOB	Erected	FOB	Erected
90.0-94.9	64.7 (2)	59.3 (1)	33.8 (1)	101.1 (6)	25.2 (1)	69.2 (2)	25.8 (3)	No data
95.0-98.9	75.4 (15)	91.6 (5)	61.1 (10)	88.6 (12)	37.1 (6)	62.4 (9)	31.6 (21)	55.3 (16)
99.0+	98.0 (4)	204.5 (5)	62.7 (4)	103.5 (5)	44.3 (9)	82.7 (9)	34.2 (23)	55.5 (17)

Note: (a) Costs are cents/ACFM.
(b) Numbers in parentheses are sample size, i.e., no. of installation contract prices averaged to obtain indicated costs/ACFM (all precipitator manufacturers represented).

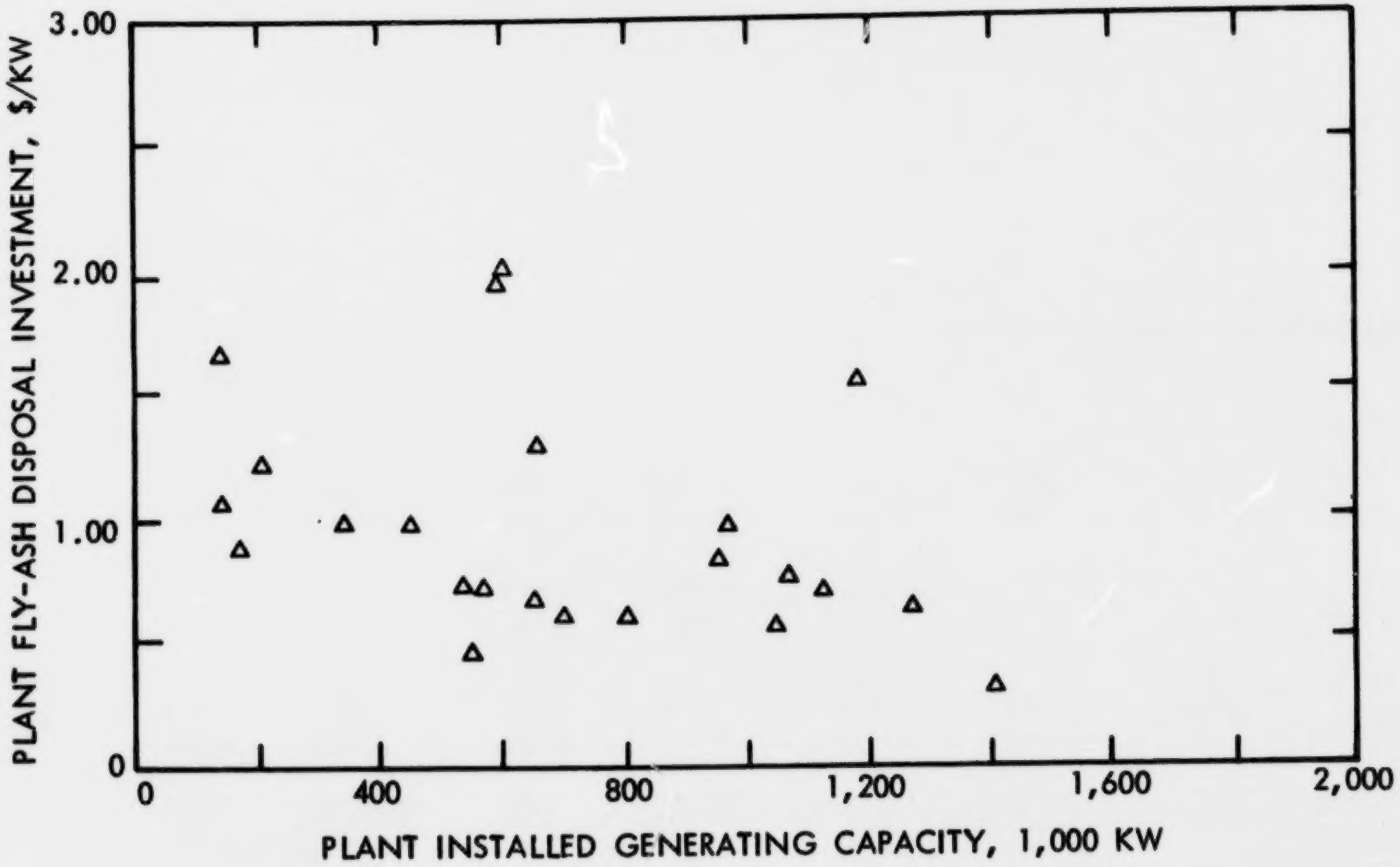

Figure 6-4 - Plant Fly-Ash Disposal Investment[7]

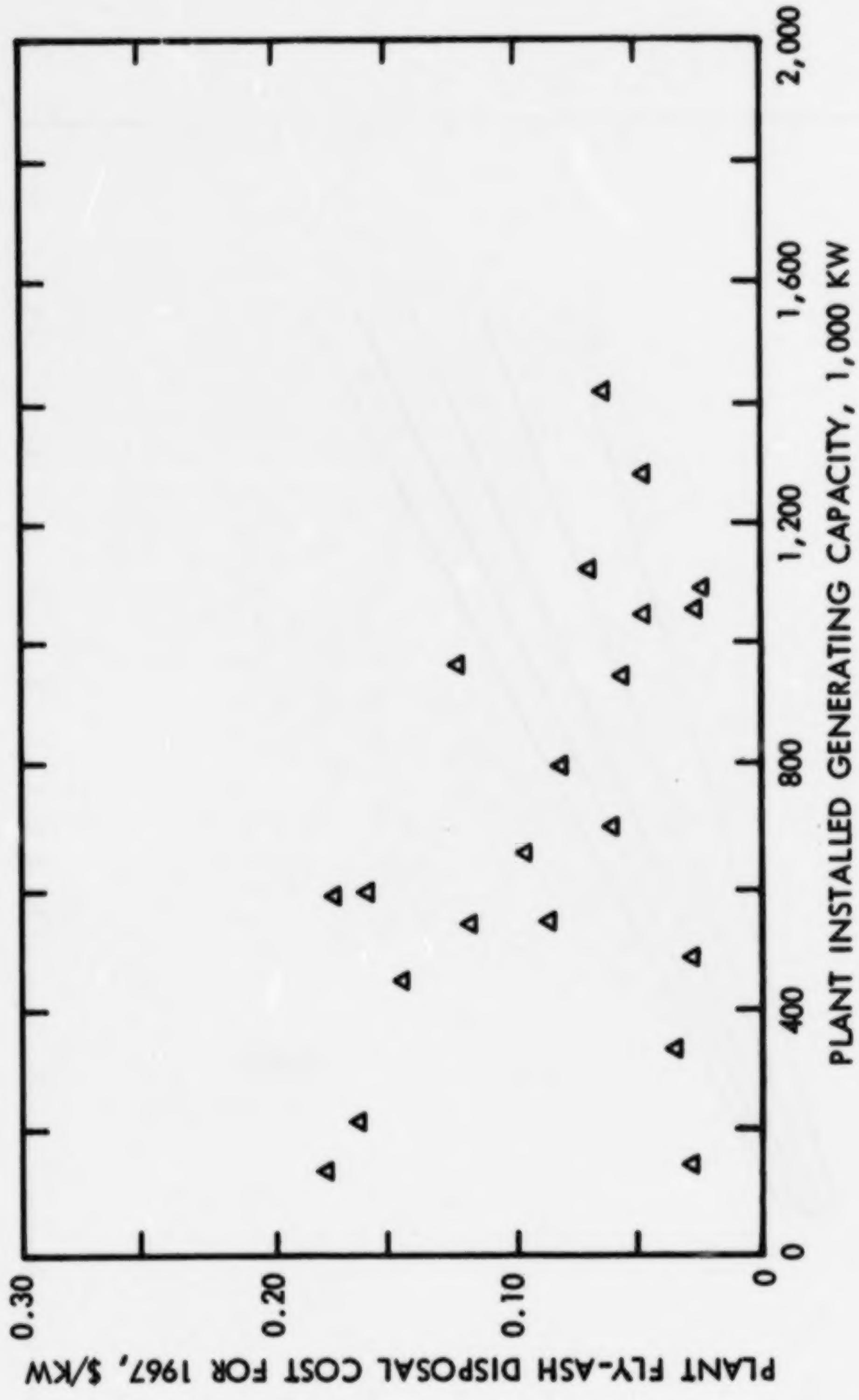

Figure 6-5 - Plant Fly-Ash Disposal Cost for 1967[7]

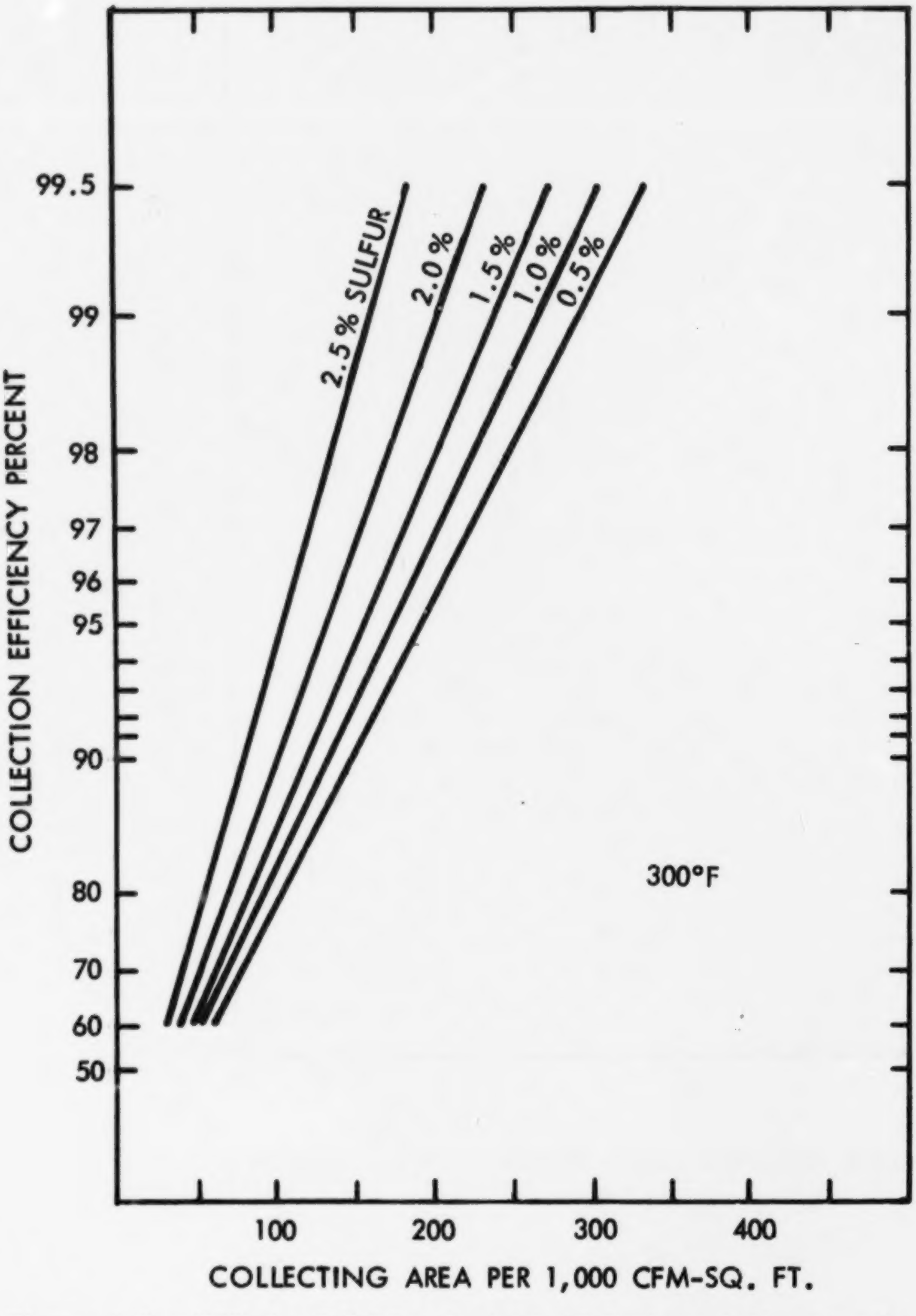

Figure 6-6 - Effect of Sulfur Content of Coal on Collecting Area Required in Electrostatic Precipitator

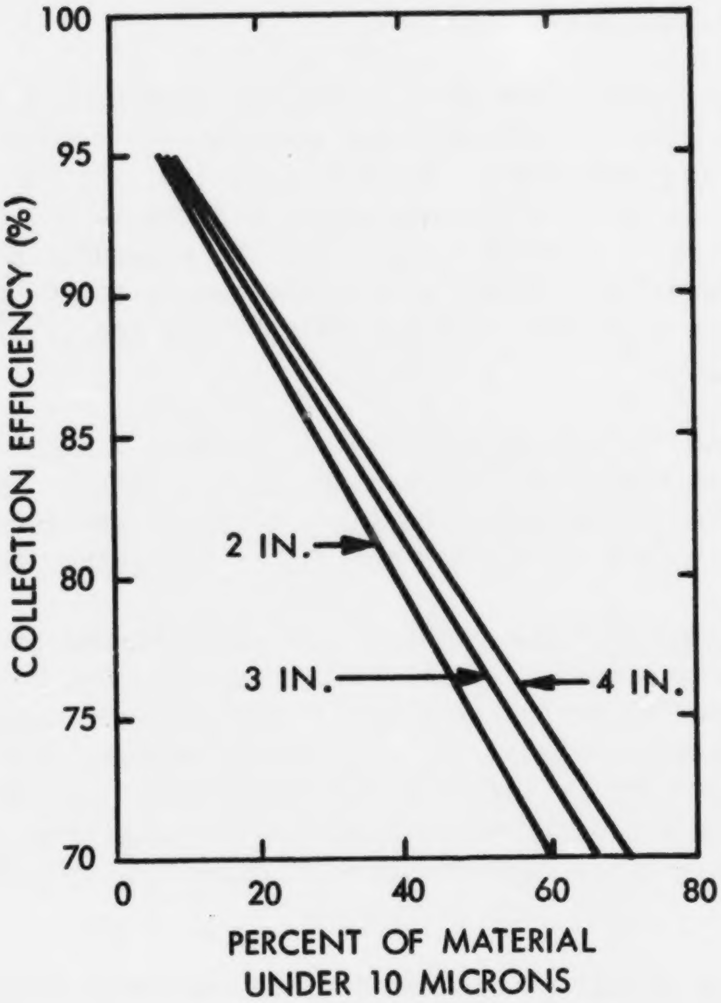

Figure 6-7 - Multiclone Collection Efficiency - Fly Ash. (As a function of particle size at pressure drops of 2 in., 3 in. and 4 in. of H_2O.)[13]

6.2.4.1.4 Wet scrubbers: Sprays are used to a limited extent in the stacks of coal-fired units to control particulate emissions during soot blowing. The problems that limit the use of wet scrubbing include high corrosion rates, high or fluctuating pressure drops, adverse effects on stack gas dispersion, and waste disposal.

A turbulent contact absorber system has undergone testing for absorption of SO_2 in alkaline solution and simultaneous removal of fly ash for a coal burning power plant. With this system, fly ash collection efficiencies of 98% and overall SO_2 removal of 91% can be expected at wet scrubber pressure drops of about 4.5 in. w.g. For a generating capacity of 25 megawatt equivalent to 100,000 cfm of flue gases at 300°F, the investment and operating costs are approximately $10/kw and $1.17/ton of coal, respectively.[14]

Two limestone injection SO_2 removal systems, designed by Combustion Engineering, have been installed on operating boiler units. This design incorporates a marble-bed wet scrubber having $<$ 6 in. of pressure drop and is guaranteed to remove 83% of the SO_2 and 99% of the particulate matter.[17]

6.2.4.2 Oil-Fired: The combined ash and unburned particulates in exhaust gases from gaseous or liquid fuel combustion are not likely to exceed local air pollution control statutes. For instance, the efficient burning of a common heavy residual oil of 0.1% ash results in a stack gas concentration of only 0.030 grain/scf at 12% CO_2. Nevertheless, particulates from oil burning are still principally in the submicron range (0.4 μ), and are in sufficiently large concentration to cause perceptible light scattering.

The only air pollution control devices that have found ready acceptance on oil-fired power plant boilers are dust collectors used to control particulates during soot blowing. This equipment serves principally to collect particulate matter larger than 10 μ. Small-diameter multiple cyclones are the most common soot-control devices installed. The emission from an oil-fired unit without special collection equipment is comparable to a coal-fired unit of better than 99% collection efficiency.[10]

The use of an electrostatic precipitator for particulate removal on an oil-fired steam generator was tested on a pilot unit and a prototype unit. Although control was outstanding on the pilot unit, stack emissions from the full-scale unit did not comply with opacity regulations.[15]

6.2.4.3 Gas-Fired: Control equipment has not been utilized on natural gas equipment.

6.3. INDUSTRIAL POWER GENERATION

Large industrial plants may generate their own electric power or process steam by the combustion of coal, fuel oil, and gas. Emissions from these combustion units parallel those discussed under electric utilities (Section 6.2) but are lower in total quantity because of a smaller quantity of fuel burned.

6.3.1 Fuel Type

6.3.1.1 Coal-Fired: The stoker-type boiler is the dominant unit used in industrial plants. Stoker units accounted for about 70% of the coal burned by industrial plants in 1968. Pulverized units (20%) and cyclone (10%) accounted for the remaining coal consumption. The pulverized and cyclone units are generally associated with larger industrial complexes, and are similar in design to those discussed under electric utilities.

Stoker units used include:

1. Spreader stoker,
    a. Traveling grate
    b. Stationary or dumping grate
    c. Vibrating grate
    d. Reciprocating grate
2. Chain or traveling grate,
3. Water-cooled vibrating grate,
4. Multiple retort underfeed, and
5. Bituminous Coal Research Automatic "Packaged".

Spreader-stoker units were described in Section 6.2.1.1. Traveling grate and chain-grate units have moving grates. These grates move from the front to the rear and carry coal from the hopper in front through a grate into the combustion zone. The fuel bed burns progressively to the rear, where the ash is continuously discharged. Older units with natural draft are fast disappearing; modern units have zone-controlled forced draft. Complete combustion-control systems are utilized and overfire air, especially in the front wall, is an aid to burning the volatiles in the fuel.3/

The water-cooled vibrating grate unit consists of a water-cooled grate structure on which the coal moves from the hopper at the front of the boiler through the burning zone by means of a high-speed vibrating mechanism automatically operated on a time-cycling control. As in the traveling grate, the fuel bed progresses to the rear, where the ash is continuously discharged. Forced air is zone-controlled and regulated, along with the complete coal and air system, through an automatic combustion-control regulator.3/

Multiple-retort underfeed boilers usually consist of several inclined retorts side by side, with rows of tuyeres in between each retort. Coal is worked from the front hopper to the rear ash-discharge mechanisms by pushers. The forced-air system is zoned beneath the grates by means of air dampers, and the combustion control is a fully modulating system. In the larger furnaces the walls are water-cooled, as are the grate surfaces in some units. Multiple-retort underfeed stokers are declining in use, giving way to spreaders and traveling-grate units.

The BCR automatic packaged boiler is a complete steam or hot water generating system, incorporating a water-cooled vibrating grate as the firing mechanism. Coal is delivered from the storage bin to a hopper from which it travels on the vibrating grate to the fuel bed. Ash is discharged automatically by means of a screw conveyor. The unit has completely automatic combustion controls so that coal feed to the hopper from the bin and ash discharge is coordinated with load conditions. Forced and induced draft fans are used.3/

6.3.1.2 Oil-Fired: Large industrial complexes will use essentially the same design of furnace as is used in electric utility plants. These units are discussed in Section 6.2.1.2. Smaller industrial operations utilize lower capacity units with attendant lower flame temperatures. In many cases less attention is given to treatment of fuel and regulation of combustion air for small units. Neglecting either one often results in reduced combustion efficiency.4/ Boiler types used in smaller units are: (1) steam atomizing, (2) pressure atomizing, and (3) centrifugal atomizing.

6.3.1.3 Gas-Fired: No detailed information was found on gas-fired units in industrial applications.

6.3.2 Emission Rates

6.3.2.1 Coal-Fired: Emissions from coal-fired industrial units are affected by the same factors discussed in Section 6.2.2.1 for electric utility plants. Emission rates are summarized in Table 6-1. Emissions currently total about 2.6 million tons/year with stoker-fired units accounting for about 85% (2.2 million tons/year).

6.3.2.2 Oil-Fired: The fly ash loadings for industrial sources may be slightly higher than those for the larger electric-generating plants. Emission levels are dependent upon combustion efficiency and rate of build-up of boiler deposits. Table 6-1 summarizes emission levels for oil-fired industrial boilers. Current emissions are estimated at about 100,000 tons/year.

6.3.2.3 Gas-Fired: Meager data exist on emissions from gas-fired units. Available information on emission rates is tabulated in Table 6-1. Particulate emissions are estimated to be about 85,000 tons/year.

6.3.3 Characteristics of Effluents from Industrial Boilers

6.3.3.1 Coal-Fired: The characteristics of effluents from industrial coal-fired units would parallel those from electric-utility sources. Some differences in composition and particle size of the fly ash will occur because of the differences in boiler types employed in industrial plants.

6.3.3.2 Oil-Fired: Characteristics of emissions from oil-fired industrial boilers differ in minor respects from those of electric-utility boilers. Table 6-2 summarizes available data for these sources.

6.3.3.3 Gas-Fired: No detailed data were found on emissions from gas-fired boilers.

6.3.4 Control Practices and Equipment for Industrial Boilers

6.3.4.1 Coal-Fired: Control equipment for coal-fired industrial boilers is very similar to that employed by electric utilities. Cyclones, multiclones and electrostatic precipitators are used in both groups although the use of electrostatic precipitators has not been as prevalent for industrial boilers.

The increased emphasis on reducing air pollution has apparently prompted many of the industrial coal-fired boiler operators to switch over to oil or gas. This route to control may be a simpler matter for the industrial operator than for the electric utility operator who is consuming larger quantities of fuel.

6.3.4.2 Oil-Fired: The use of control devices on oil-fired units is usually limited to periods when soot-blowing operations are in progress or in areas where restrictive legislation requires low particulate loadings and low opacity of stack effluents. Multiple cyclones and electrostatic precipitators have been used for these purposes.4/

6.3.4.3 Gas-Fired: Control equipment has not been utilized on natural-gas equipment.

6.4. COMMERCIAL, INSTITUTIONAL, AND RESIDENTIAL FURNACES

Commercial, institutional and residential furnaces are primarily used for space heating. The general character of emissions from these sources would parallel that of electric utility and industrial sources, with allowance made for differences in furnace types and operating procedures. In general, combustion efficiency will be lower in these units and outlet grain loadings higher as a result.

6.4.1 Fuel Type

6.4.1.1 Coal-Fired: Small stoker-type boilers are the main units used in commercial, institutional and residential operations. In some cases hand-fired equipment may be employed, but such installations are fast disappearing, and are being replaced with automatic firing.

Stoker units include:

1. Underfeed stokers,
    a. Single retort (residential)
    b. Multiple retort
2. BCR Auto Packaged, and
3. Small spreader stoker
    a. Stationary or dumping grate
    b. Water-cooled vibrating grate.

In the residential underfeed stoker, the coal is fed from a hopper or directly from the coal storage bin to the retort by a continuous, rotating screw. Coal rises into the firing zone from underneath: thus the term "underfeed firing". Air is delivered to the firing zone through tuyeres (grate openings), also from underneath the actively burning bed. The coal and primary air control is "all on" or "all off". Ash is removed as a clinker from a refractory hearth through the furnace firing door.

The general arrangement of the single retort unit for commercial and institutional use is similar to the residential unit, with "dead" plates replacing the refractory hearth. As sizes become larger, screw feeders are replaced by a mechanical ram, which feeds coal to pusher blocks that distribute the coal in the fire box. Ash is discharged by side-dump grates. Modulating combustion controls, i.e., variable control of both fuel and air rates, are often used. Forced draft is automatically regulated, and separate over-fire air systems are used, particularly when on-off controls are used. A bridge wall retains the coal over the stoker grates.[3]

The multiple-retort, BCR automatic packaged boiler, and spreader-stoker units are described in Section 6.3.1.1.

6.4.1.2 Oil-Fired: Boiler types are similar to the small units discussed in Section 6.3.1.2.

6.4.1.3 Gas-Fired: No pertinent information is available on gas-fired units for these installations.

6.4.2 Emission Rates

Data are meager on emissions from all types of units used in these facilities. In general, lower combustion efficiency than that experienced for utilities or industrial units is expected to lead to increased outlet grain loadings.

6.4.3 Characteristics of Effluents

No pertinent data on effluent characteristics were found for this class of furnaces.

6.4.4 Control Practices and Equipment

Control equipment is not generally used on these small furnaces. Reference 16 discusses the use of various combustion-improving devices to reduce emissions of smoke, carbon monoxide, nitrogen oxides, and total gaseous hydrocarbons from high-pressure atomizing-gun burners used in domestic oil-fired furnaces. The devices (primarily improved nozzles) were designed to improve combustion in older inefficient furnaces. Laboratory tests indicated that the devices offer potential for reducing levels of pollutants.

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CHAPTER 7

CRUSHED STONE, SAND, AND GRAVEL INDUSTRIES

7.1 INTRODUCTION

The conversion of naturally occurring minerals into crushed stone sand, and gravel involves a series of physical operations. Quarrying, transportation, crushing, size classification, and drying are common to almost all mineral production procedures. Air pollution problems may be created by all of these operations. The dust emitted is usually a heavy dust released at ambient temperature, and these emissions can be considered to be a nuisance to the community. Processing methods, particulate emission sources, emission rates of individual particulate sources, the characteristics of source emissions, and control practices and equipment are discussed in the following sections.

7.2 CRUSHED STONE

7.2.1 Production Process

The initial step in the processing of crushed stone occurs at the quarry site. Rock and stone products are loosened by drilling and blasting from their deposit sites. Primary drilling, primary blasting, and secondary blasting or breakage comprise the principal steps in the quarry operation. The secondary blasting operation in many quarries is now either eliminated by better fragmentation during primary blasting, or by the use of "drop ball" cranes. Tractor-mounted air or hydraulic operated "rock-splitters" have proven satisfactory for some operations.1/

The broken rock or stone is transported from the quarry to the processing plant. Transport is usually by truck or heavy earth moving equipment. The processing of stone includes such operations as drying, crushing, pulverizing, screening, and conveying. Primary crushers will normally reduce stone to 1-3 in. in size. Secondary crushers are used to reduce stone to sizes below 1 in. Following the processing operations, the stone or rock is loaded for shipment to the customer or sent to storage.

7.2.2 Emission Sources and Rates

Particulate emission sources in the crushed stone industry can be divided into two categories; first, sources associated with the actual

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quarrying, crushing, screening, and processing operations; and second, "fugitive" sources involving reentrainment of previously settled dust. These fugitive sources include vehicle traffic on temporary roads, transfer operations, and stockpiles.

The use of pneumatic drilling and cutting as well as the blasting and transferring can cause considerable dust formation at quarry sites. The transport of stone by vehicle creates dust from unimproved roads. No quantitative data is available on emission rates from these sources.

Rock processing operations (i.e., crushing, pulverizing, classifying) are potential dust sources. Dust is discharged from crushers and grinder inlet and outlet ports. Factors affecting emissions include moisture content of the rock, type of rock processed, amount of rock processed, and type of crusher employed.

Some minerals require drying prior to processing. Dryers are usually direct-fired, either parallel or counter flow, rotary units. Particulate emissions from dryers can be significant, and the amount emitted varies with type of mineral processed, degree of drying, and dryer type.

A major "fugitive" dust source is stockpiles (i.e., windblown dust). Losses vary with size of stored material, density of material, moisture content, and wind speed.

Actual test data on emissions from the above sources are limited. The limited emission data are presented in Table 7-1. The factors used in estimating the particulate emissions from the crushed stone industry were obtained from Reference 2. Table 7-1 does not include dust blown from stockpiles. Stockpile losses due to wind erosion have been estimated at 0.5% of finished product for crushed stone.[2/] The potential amount of dust that could arise from stockpiles in crushed stone storage areas is about 3.1 million tons per year. Factors which would reduce this estimate are: (1) the amount of product which is loaded for shipment directly from processing without being sent to stockpiles; (2) the amount stored in bins and silos; and (3) amount of product which has sufficient moisture content at the time of discharge to stockpiles to inhibit the formation of dust by wind erosion.

No estimate has been made of dust emissions from quarrying or from vehicle traffic over unpaved or paved plant roads.

7.2.3 Effluent Characteristics

Meager data exist on the physical and chemical properties of dust emitted in crushed stone operations. It is usually a heavy dust emitted at

TABLE 7-1

PARTICULATE EMISSIONS
CRUSHED STONE, SAND AND GRAVEL

Source	Quantity of Material	Emission Factor	Efficiency of Control C_c	Application of Control C_t	Net Control $C_c \cdot C_t$	Emissions (tons/year)
I. Crushed Stone						
A. Primary crusher	681,000,000 tons (cement, lime & dolomite not included)	0.5 lb/ton of rock[a]				
B. Secondary crushing & screening		1.5[a]				
C. Tertiary crushing & screening		6.0[a]				
D. Fines milling		6.0[a]				
E. Re-crushing & screening		1.0[b]				
		15.0[a]	0.80	0.25	0.20	4,100,000
F. Conveying, general screening, etc.		1.7 lb/ton of product	0.80	0.25	0.20	454,000
G. Dryers		--	--	--	--	--
II. Sand & Gravel - crushing and screening	918,000,000 tons	0.1 lb/ton of material				46,000
III. Quarrying						
A. Drilling		--	--	--	--	--
B. Blasting		--	--	--	--	--
C. Loading - unloading		--	--	--	--	--
IV. In-Plant Vehicle Traffic		--	--	--	--	--
		Total for Crushed Stone, Sand and Gravel				4,600,000

---

[a] Pounds/ton of rock through the primary crusher.

[b] Listed emission factor is 5 lb/ton of rock re-crushed. Twenty percent of product is assumed to be re-crushed.

ambient temperatures. The majority is fairly coarse and contains some moisture. Figure 7-1 presents particle size data for the particulates emitted from a jaw crusher and a conveyor system.

7.2.4 Control Practices and Equipment

Control measures consist of wetting and sprinkling to minimize dusting and proper loading and evacuation to collect dust from crushing and screening equipment and transfer points. Cyclones and water spray chambers are the present chief means of collection of this dust. Bag filters or high efficiency water scrubbers are used in locations where stringent emission standards must be met.

7.2.4.1 Quarry Operations: There are many sources of dust associated with crushed stone operations and most of these are of the "fugitive" type. Blasting is one of these sources which occurs intermittently.

In conventional mining of coal, water-filled plastic bags are used for stemming dust emissions from blast holes. Their use in conjunction with an air-and-water blast results in a considerable reduction of the dust from blasting.[3] This technique may be applicable to blasting operations in stone quarries.

A method of suppressing dust from dry percussion drilling in quarries and open pit mines has been developed. Water with an added wetting agent is introduced into the air used for flushing the drill cuttings from the hole. Dilution ratios range from 800 to 3,000 parts of water to one of surfactant. The proper amount of solution, about 7 gal/hr for a 3-1/2 in. dia. hole, causes the drill cutting to be blown from the hole as damp dust-free pellets.[3]

For primary blowing operations, it has been reported that initiation of detonation with multi-delay devices and the complete combustion of the explosive compound result in low dust emission.[1]

7.2.4.2 Transport Operations: The loading and unloading of blasted stone also usually releases dust into the atmosphere. Wetting of the broken stone can effectively decrease the dust emission but this is not a common practice. Wetting the surface of a load in a transport vehicle will reduce windage loss during transport.

The transport of stone by vehicle creates airborne dust from unimproved roads. This can be minimized by frequent wetting of the road. Oiling or wetting with $CaCl_2$ can reduce the required frequency of wetting.

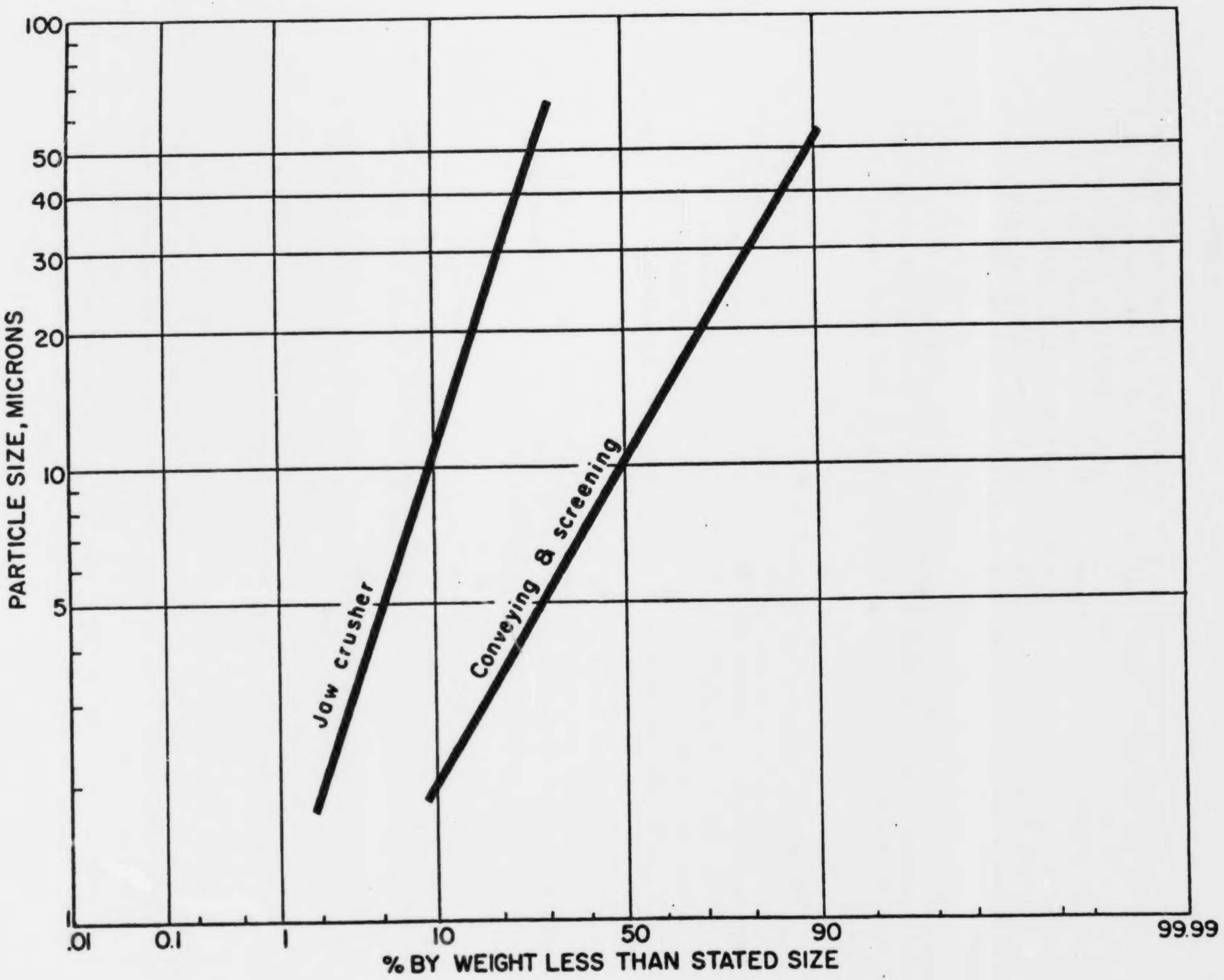

Figure 7-1 - Particulate Size from Rock Processing Operations[2]

No estimate has been made of dust emissions from quarrying or from vehicle traffic over unpaved or paved plant roads.

7.3.3 Effluent Characteristics

Limited data were found on the characteristics of effluents from sand and gravel plants. Stock sampling data for sand and gravel dryers, obtained from state control agencies,[9,10] indicated that outlet grain loadings ranged from 5.8 to 38 grains/ft^3. Mass median particle size of the particulates emitted from the dryers varied from 3.5 to 9.4 μ.

7.3.4 Control Practices and Equipment

Specific information on control practices and equipment utilized in sand and gravel plants is limited. Since many of the operations parallel those of the crushed stone industry, similar control practices and equipment are undoubtedly employed.

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CHAPTER 8

OPERATIONS RELATED TO AGRICULTURE

8.1 INTRODUCTION

The agriculture industry as considered here includes such diverse operations as field burning, grain elevators, feed mills, and cotton gins. Obviously, emissions from these operations are highly variable.

Open burning of agricultural wastes is practiced in many areas as the most practical means of clearing the land of these wastes. This practice can contribute a high concentration of pollutants to the atmosphere. Grain handling facilities constitute a major dust problem in some urban areas. Furthermore, in less densely populated areas a grain facility may be a nuisance to people in the immediate vicinity. Cotton gins also present primarily a localized air pollution problem.

Various phases of the agriculture industry, particulate emission sources, particulate emission rates, effluent characteristics, and control practices and equipment are discussed in the following sections.

8.2 AGRICULTURAL FIELD BURNING

Disposal of agricultural wastes is imperative because the refuse piles act as reservoirs of horticultural diseases and agricultural pests. Open burning is currently the most practical means of accomplishing this disposal.

Emissions into the atmosphere from the burning straw and stubble are characteristic of vegetative plant sources generally. Cellulose and lignin are the primary constituents of plants. Emissions consist of smoke, made up of carbon particles of varying sizes, ash, and certain gases. Most of the carbon particles are minute in size and indistinguishable without visual aid, while others are readily visible. The former are a major factor in reduced visibility, while the larger particles, which settle out more readily, are factors in soiling and deposits on property. The principal gases emitted are the organic hydrocarbons, carbon dioxide, carbon monoxide and oxides of nitrogen.[1] Open burning emissions are affected by many

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variables including wind, ambient temperatures, moisture content of the fuel burned, size and shape of fuel, and compactness of fuel bed. Table 8-1 gives typical data for particulate emissions from rye-grass burns and Table 8-2 summarizes emission rates. It is estimated that agricultural field burning emits about 2.4 million tons of particulate/year.

TABLE 8-1

PARTICULATE EMISSIONS FROM RYE-GRASS BURNS[1]/

Grass	Variable	Low	Average	High
Annual	Suspended particulate, mg/m^3	11.4	25.6	46.8
Annual	Percent organic matter in smoke	13.3	37.4	63.9
Perennial	Suspended particulate, mg/m^3	20.4	39.4	56.3
Perennial	Percent organic matter in smoke	19.9	38.8	72.8

TABLE 8-2

PARTICULATE EMISSIONS FROM
OPERATIONS RELATED TO AGRICULTURE

Source	Quantity of Material	Emission Factor	Efficiency of Control C_c	Application of Control C_t	Net Control $C_c \cdot C_t$	Emissions (tons/yr)
I. Burning of Stubble	280,000,000 tons of stubble	17 lb/ton of stubble burned	0.0	0.0	0.0	2,400,000
II. Grain Elevators	177,000,000 tons of grain					
A. Terminal Elevators						
1. Shipping or Receiving		1 lb/ton of grain handled				
2. Transferring, Conveying, etc.		2 lb/ton of grain handled				
3. Screening and Cleaning		5 lb/ton of grain handled				
4. Drying		6 lb/ton of grain handled				
B. Country Elevators						
1. Shipping or Receiving		5 lb/ton of grain handled				
2. Transferring, Conveying, etc.		3 lb/ton of grain handled				
3. Screening and Cleaning		8 lb/ton of grain handled				
4. Drying		7 lb/ton of grain handled				
Total for Grain Elevators			0.70	0.40	0.28	1,700,000
III. Cotton Gins	11,000,000 bales					
A. Trailer Unloading		5 lb/bale				
B. Cleaners		2 lb/bale				
C. Stick and Bur Machine plus Huller Front and Mote Discharge Stand		3 lb/bale				
D. Lint Cleaner		1 lb/bale				
E. Condenser		1 lb/bale				
Total for Cotton Gins		12	0.80	0.40	0.32	45,000
IV. Feed Mills						
A. Alfalfa Dehydrators	1,600,000 tons of dry meal					
1. Primary Cooling Cyclone		11 lb/ton of dry meal				
2. Secondary Cooling Cyclone		4 lb/ton of dry meal				
3. Air-Meal Separator						
a. Cyclone		47 lb/ton of dry meal				
b. Cyclone + Skimmer		9 lb/ton of dry meal				
4. Pellet-Meal Separator		2 lb/ton of dry meal				
5. Pellet Re-Grinder		2 lb/ton of dry meal				
Total for Alfalfa Dehydrators		50 (as an average)	0.85	0.50	0.42	23,000
B. Wheat Mill-Feeds	4,490,000 tons	1% of end product	--	--	0.42	26,000
C. Gluten Feed and Meal	1,515,000 tons	1% of end product	--	--	0.42	9,000
D. Rice Mill-Feeds	476,000 tons	1% of end product	--	--	0.42	3,000
E. Brewers' Dried Grains	336,000 tons	1% of end product	--	--	0.42	2,000
F. Distillers' Dried Grains	447,000 tons	1% of end product	--	--	0.42	3,000
G. Dried Beet Pulp	1,100,000 tons	1% of end product	--	--	0.42	6,000
Total for Feed Mills Other Than Alfalfa						49,000
V. Flour Mills	112 lb. per capita	--	--	--	--	--
			TOTAL FOR LISTED OPERATIONS			4,217,000

8.3 GRAIN ELEVATORS

Grain elevators are primarily transfer and storage units and are classified into two categories. These are the smaller more numerous country elevators and larger terminal elevators. In addition many elevator locations also contain feed manufacturing facilities. Particulate emissions occur because of the dry, light nature of most grains and the way they are handled via pneumatic and mechanical conveyors. A wide variety of grain-handling configurations are possible at elevator sites depending on the number and quantity of grains handled, and the amount of processing required. At grain elevator locations any or all of the following operations can occur:

Receiving, transfer and storage
Cleaning
Drying
Milling and grinding.

Receiving and transfer operations are accomplished by unloading the grain, usually by dumping into a bin followed by conveyor belt or pneumatic transfer. Cleaning operations are designed to eliminate impurities such as sticks, stones, and other foreign matter. Both screening and air classifiers are used to separate grain and foreign matter.

8.3.1 Emission Sources and Rates

Emissions from grain operations may be separated into those occurring at all elevators involving transfer losses, and those occurring at processing operations such as cleaning, drying, and grinding. Emissions are greatest at the loading and unloading areas, especially when these operations are carried out in the open. Falling or moving streams of particles inspirate a column of air moving in the same direction. When this moving mass of particles strikes an immovable object, the energy expended causes extreme air turbulence and a violent generation of dust occurs. This undesirable situation occurs when trucks and rail cars are dumped into deep hoppers and also when rail cars and the holds of ships are loaded.

Lesser sources of dust emissions in transfer operations are conveying equipment and storage bins. Belt conveyors have less rubbing friction than either screw or drag conveyors and generate less dust. Dust emissions usually occur at belt transfer points as materials fall onto or away from a belt. The discharge points of pneumatic conveying equipment are also potential sources of dust emissions. Storage bins vent dust-laden air from two sources. One source is air displaced during loading operations. As the incoming material falls freely from a spout at the top of the bin, dust is mixed with the air in the bin. The other source is air inspirated by the flow of incoming material.

Factors affecting emissions from grain elevator transfer operations include the types of grain, the moisture content of the grain (usually 10-20%), amount of foreign material in the grain (usually 5% or less), the amount of moisture in the grain at the time of harvest (hardness), the amount of dirt included with the grain during harvesting, and the degree of enclosure at loading and unloading areas.[2]

The grain processing operations may include wet and dry milling (cereals), flour milling, oil-seed crushing, and distilling. Wet milling by its nature is not conducive to major dust formation, although dust may escape from dryer cyclones. Dry milling, however, is somewhat more dusty in its operation. Most handling and transfer in these operations is pneumatic, allowing good dust control. Oil-seed crushing generally is not conducive to major dust generation, but losses can occur from extracting and drying operations and from cyclone collectors used on these operations. Grain distilling operations also are not conducive to major dust formation although particulates can escape during unloading of grains and be entrained in the gaseous discharge from cooling operations. The major problem with these operations is odor emissions.[2]

Drying is usually accomplished in rotary, column, or shelf dryers using heated air as the drying medium. The material emanating from the dryers is generally not classified as dust but rather chaff or, in the case of corn, "beeswing." Although the particle size is large, it is extremely light and filmy. This material will carry for miles on a windy day if it is released from a source sufficiently high above the ground.[3]

Grinding may be done in a variety of devices in either a wet or dry state. Common devices used include hammer mills and rollers. Many of the large terminal elevators also process grain at the same location.

Factors affecting emissions from grain processing operations include the type of processing (wet or dry), the amount of grain processed, the amount of cleaning, the degree of drying and heating, the type of dryer, the amount of grinding, and the type of grain.[2]

Emission rates for grain elevators are summarized in Table 8-2. Current particulate emissions total 1.7 million tons/year.

8.3.2 Effluent Characteristics

Available data on the chemical and physical characteristics of effluents from grain elevators are summarized in Table 8-3. Particulates emitted during railroad car loading of oats and wheat have a geometric mean size of 3.1 and 2 μ. Grain dust presents a high explosive hazard.

8.3.3 Control Practices and Equipment

Air pollution from feed and grain mills consists entirely of dusts. These dusts, though varied, may be collected by inertial devices and fabric filters.

For receiving hoppers used for unloading, the best method of hooding is to exhaust air from below the dump grating to a fabric filter or cyclone-filter combination.[4] One of the most difficult to control emission sources is that occurring when grain is poured into the hold of a ship.[5]

The duct work for a dust-collection system generally is sized based on the volume of air necessary for each hood inlet and pickup point, and a base velocity of 4,000 ft/min in the duct. Velocities of < 3,500 ft/min will permit settling of dust in long horizontal ducts. If dust settles and accumulates in duct work, it provides a harborage and point of insect infestation. Careful attention should be given to design of duct work to avoid projections in the duct which will permit accumulation of dust and subsequent infestation by insects.[6]

One development reported in a recent article[5] is a completely enclosed belt conveyor. The basement of the storage elevator, which houses the conveyor, is kept under slight positive pressure so that no dust can leak from inside the conveyor.

8.3.3.1 Cyclones: Cyclones are used with great versatility in grain elevators and in feed mills. Nearly all cyclones are of the simple, low or medium efficiency types.

8.3.3.2 Baghouses: Fabric filters can provide high efficiency dust collection for most services associated with feed and grain operation. However, they do not find application in grain drying due to the high moisture content of the effluent gases from the dryer.

TABLE 8-3

EFFLUENT CHARACTERISTICS - OPERATIONS RELATED TO AGRICULTURE+

A. Particulate (Part I)

Source	Particle Size	Solids Loading	Chemical Composition	Particle Density	Electrical Resistivity	Moisture Content	Toxicity
Agriculture Industry							
1. Field burning							
a. Rye-grass field	Suspended particulates: mean particle size: 0.5	11-56* avg., 32.5	Carbon, ash				
2. Grain elevators							
a. Railroad car loading	Optical: Oats Geometric mean size, 3.1 (1 test) Wheat: geometric mean size, 2.1 (1 test)	248*	See Table 8-4 for detailed composition	1.4			Grain dust not considered toxic, but may cause respiratory symptoms and skin rash on prolonged exposure
b. Conveyor system (1 plant)	Screen analysis: 6.4 < 44, 25.6 < 74, 43 < 104						
c. Cleaning			Chaff, bran, weed seed, pollen, dirt, insect parts				
d. Drying			Chaff				
3. Flour mill		4-35	Flour dust				
4. Feed mill							
a. Feed barley hammermill				1.8			
5. Alfalfa dehydrating mill							
a. Primary cooling cyclone		0.1-0.2					
b. Secondary cooling cyclone	Average equivalent Stokes' dia., 5-7	0.1-0.4		1.23			
c. Air meal separator	Average equivalent Stokes' dia., 1.5-3	0.2-2.3	See Table 8-5 for detailed composition	1.32			
d. Pellet meal air separator	Average equivalent Stokes' dia., 6-10	0.1-0.4		1.31			
e. Pellet regrind air separator	Average equivalent Stokes' dia., 3	1.7		1.24			
6. Cotton ginning							
a. Gin		0.0019-0.55 (dependent upon sampling point)	Trash, dust, lint, and pesticide residue				
b. Incinerator			Fly ash, smoke, arsenic				Toxic due to arsenic content

A. Particulate (Part II)

Source	Solubility	Wettability	Hygroscopic Characteristics	Flammability or Explosive Limits	Handling Characteristics	Optical Properties	Odor
Agriculture Industry							
1. Field burning							
2. Grain elevators				Grain dust presents a high explosive hazard	Grains are gennerally not abrasive, sticky, or corrosive		
3. Cotton ginning							
a. Gin					Pesticide residues may be corrosive		
b. Incinerator							Acrid

+ See Coding Key, Table 5-1, Chapter 5, page 45, for units for individual effluent properties.
* Milligrams per cubic meter.

TABLE 8-3 (Concluded)

B. Carrier Gas

Source	Flow Rate	Temperature	Moisture Content	Chemical Composition	Toxicity	Corrosivity	Odor	Flammability of Explosive Limits	Optical Properties
Agriculture Industry									
1. Field burning									
a. Rye-grass field				CO_2, CO, N_2, O_2, hydrocarbons, NO_x (see Tables 8-6, 8-7 for more detailed data)	CO-100				
2. Grain elevators									
a. Railroad car loading		Ambient							
b. Cleaning	Milo and malted barley cleaner (a) 2.6-3.7 (b) 6.8-40	Ambient							
c. Drying									
3. Flour mill									
4. Feed mill									
a. Feed barley hammermill	(a) 3.8 (b) 44 (1 mill)								
5. Alfalfa dehydrating mill									
a. Primary cooling cyclone	(a) 8-15 (b) 460-620	Dry bulb, 340 Wet bulb, 152-175	0.174-0.48** dew point 144-172	O_2, N_2, CO_2					
b. Secondary cooling cyclone	(a) 1.1-1.8 (b) 64-74	Dry bulb, 125-140 Wet bulb, 85-87	0.013-0.019** dew point 68-75						
c. Air meal separator	(a) 2.5-6.4 (b) 146-250	Dry bulb, 85-139 Wet bulb, 75-90	0.016-0.02** dew point 72-78						
d. Pellet meal air separator	(a) 3.9-4.9 (b) 100-120	Dry bulb, 110-127 Wet bulb, 94-95	0.027-0.033** dew point 82-93						
e. Pellet regrind separator	(a) 1.0 (b) 9.5	Dry bulb, 120 Wet bulb, 90	0.024** dew point 82						
6. Cotton ginning									
a. Gin	(a) 2.7-11.5			Air					
b. Incinerator				CO_2, CO, N_2, O_2, arsenic compounds and other gases characteristic of cotton waste pyrolysis					

** Pounds/pound.

TABLE 8-4

ANALYSIS OF AIRBORNE DUST COLLECTED IN VICINITY OF RAILWAY CARS DURING LOADING

	Percent by Weight	
	Oats	Wheat
Organic fraction	82.2	87.2
Inorganic fraction	17.8	12.8
Free silica in total dust	8.0	7.4
Free silica in organic fraction	2.3	1.5
Free silica in inorganic fraction	5.7	5.9

TABLE 8-5

PARTICULATE AND PRODUCT ANALYSES (ALFALFA DEHYDRATING MILL)

Particulate Source	Protein Content Percentage	Carotene Content (IU/lb)*
Company A Air meal separator	21.20	107,600
Company B Air meal separator	21.60	77,300
Company A Pellet meal air separator	18.90	88,900
Company B Pellet meal air separator	19.25	84,900
Company C Pellet regrind air separator	26.60	145,900
Product		
Company A, Pellets	15.0	100,000
Company B, Pellets	14.1	88,000
Company C, Meal	17.3	132,000

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* International Unit, IU, for carotene (pro-vitamin A) is defined as the biological activity of 0.6 μg of β-carotene.

TABLE 8-6

YIELDS OF VARIOUS POLLUTANTS FROM GRASSES[1] BURNED IN LABORATORY TOWER

Grass	Percent Moisture	Pounds/Ton of Grass Burned							C Balance (%)	NO_2 at Temp. Peak (ppm)
		Particulate	CO_2	CO	C	Sat.[a] + Acet.	Olefins	Ethylene		
					Dry Series					
Blue	5	16.5	2,786	147	18	3.3	3.1	2.4	107	72
Perennial Rye	6	12.0	2,483	104	14	2.1	3.2	1.4	100	49
Bent	2	14.0	2,557	124	14	2.1	2.0	0.9	98	21
Annual Rye	9	10.5	2,666	85	8	0.9	1.2	0.6	103	23
Fescue	9	13.0	2,737	122	12	2.5	2.4	1.2	107	45
Orchard	15	11.5	2,469	89	7	1.2	1.2	0.7	100	27
					Dry-Green Series					
Blue	23	15.0	2,407	95	8	1.0	2.0	1.2	111	44
Perennial Rye	71	26.0	678	106	19	2.4	5.6	3.4	77	4
Bent	60	24.0	1,277	109	19	2.1	5.0	3.1	94	13
Annual Rye										
1	20	9.0	1,855	56	4	0.4	1.0	0.6	103	37
2	55	11.0	969	60	6	0.8	2.4	1.8	102	--
Fescue	66	17.0	925	77	9	1.2	2.6	1.8	94	8
Orchard										
1	66	18.0	645	86	14	1.4	3.3	2.1	87	12
2	47	17.0	1,558	113	16	1.7	4.0	2.3	90	5

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[a] Without methane.

TABLE 8-7

RESULTS OF SUMMER 1967 FIELD BURNS OF VARIOUS GRASSES[1/]

Burn No.	Grass	Lb. Particulate/ Ton Fuel	Lb. CO/ Ton Fuel	Lb. HC/ Ton Fuel	Ambient Temp. (°F)	R.H. (%)	Wind Speed (mph)
2	Blue	81.23	238	14.75	89.8	32	9
3	Orchard	15.54	130	10.78	71.5	50	6
4	Orchard	8.47	140	11.18	90.2	24	6
5	Perennial Rye	10.23	133	10.68	70.5	61	5
6	Red Fescue	1.31	102	9.14	79.8	64	11
7	Red Fescue	12.65	120	9.90	88.0	34	0
9	Perennial Rye	8.78	118	9.41	80.0	51	2
10	Perennial Rye	8.75	107	9.41	80.0	62	1
11	Red Fescue	5.24	126	10.02	84.0	64	12
12	Annual Rye	3.33	108	10.27	100.0	24	9

8.4 ALFALFA DEHYDRATING MILLS

Dehydrated alfalfa is a meal product dried rapidly by artificial means at temperatures above 212°F. The general method of operation is to harvest the alfalfa with a self-propelled or tractor-drawn chopping machine. The chopped alfalfa is then transported as quickly as possible to the dehydrating plant where it is dumped onto an automatic feeding device and fed into a dryer at a uniform rate. Practically all of the dryers are of the direct-fired, rotary type. The products of combustion leave the combustion chamber of the furnace (most units are gas- or oil-fired) at a temperature in the neighborhood of 1800 to 2000°F. The chopped, wet alfalfa is discharged from the feeder into this hot flue-gas stream which is being pulled through the dryer by a fan at the outlet end. After passing through the rotating drum section, the moisture content of the material will be in the neighborhood of 7 to 9% and the flue-gas temperature will be 250 to 350°F. Customarily, the material is then blown to a primary cooling cyclone in which the dried material is separated from the now moisture-laden flue-gas stream. The effluent from this cyclone (Figure 8-1), usually billowing clouds of condensed steam, is the first of a series of atmospheric emissions from the alfalfa dehydrating plant.

From the primary cooling cyclone, the dehydrated alfalfa is passed through a secondary cooling cyclone, a grinder, and finally a third cyclone which collects the meal for bagging, bulk storage or pelletizing.

To minimize storage and shipping space requirements, the meal is often steam-extruded into pellets which are subsequently air cooled. The coolant air entrains small pellet chips and unpelletized meal. This particulate matter is then separated from the coolant air stream and recycled to the pelletizer. Separation is accomplished in a fourth cyclone, the pellet meal air separator, which constitutes a potential source of air contamination.

For formula feeds the pellets are reground, an operation found only in the larger dehydrating mills. This process consists of conveying the pellets from storage to a hammer mill, grinding the pellets into a meal, and pneumatically conveying the meal to the pellet regrind air separator, and thence to the blender, bagging equipment, or to bulk shipping facilities. The discharge from the pellet regrind air separator is a possible source of air pollution.[7]

8.4.1 Emission Sources and Rates

Objectionable emissions from alfalfa dehydrating plants include dust from the various separators, and odors from the volatile matter driven off the alfalfa with the moisture and combustion products emitted

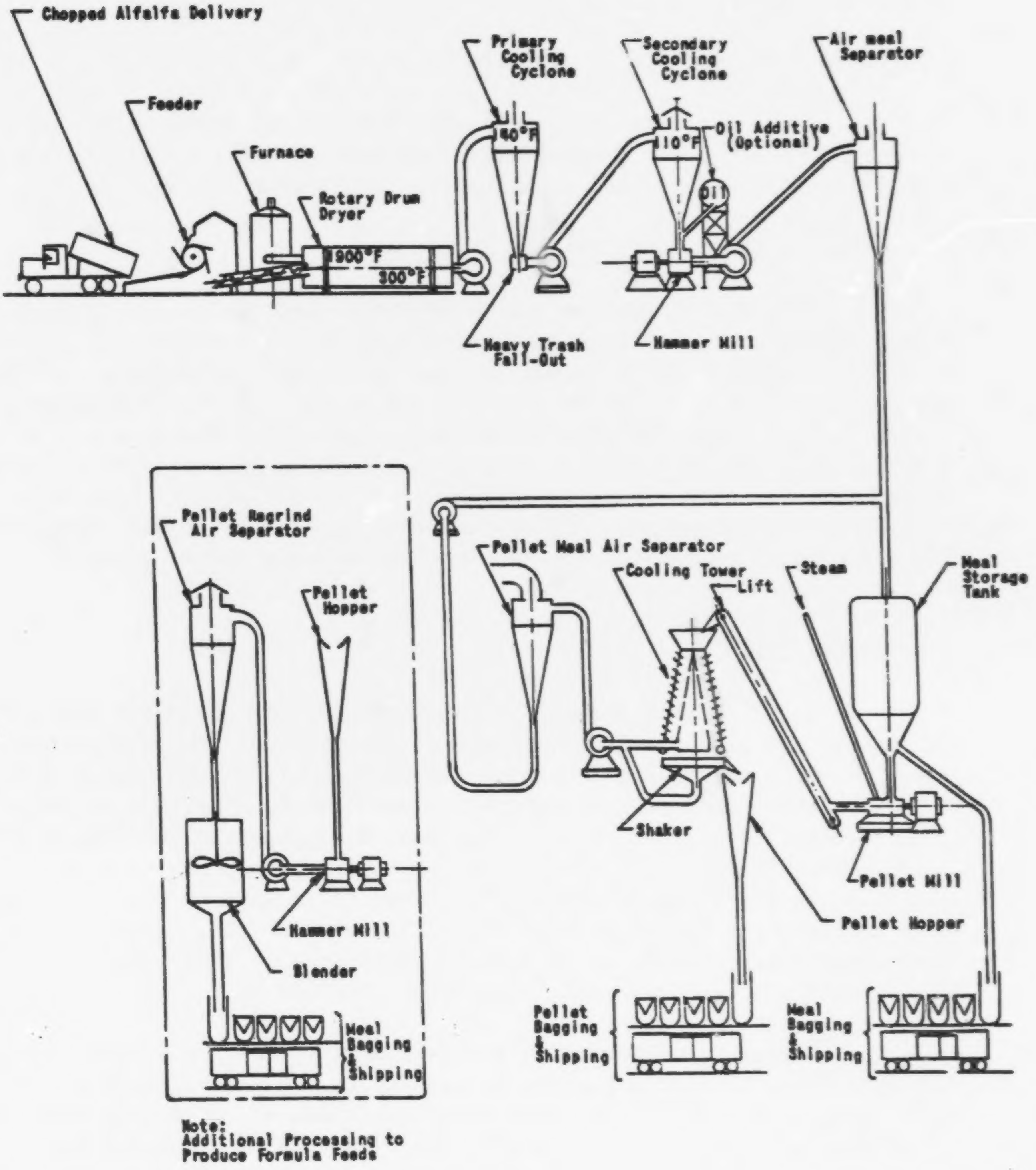

Figure 8-1 - Alfalfa Dehydrating Process Flow Diagram[7]

to the atmosphere.[7] Emission rates from alfalfa dehydrating plants are summarized in Table 8-2. Particulate emissions currently total about 23,000 tons/year.

8.4.2 Effluent Characteristics

Table 8-3 summarizes available data on the chemical and physical properties of effluents from alfalfa dehydrating plants. The average Stokes' diameter of emitted particulates ranges from 1.5 to 10 μ.

8.4.3 Control Practices and Equipment

Alfalfa dehydrating operations are a source of pollution in some areas. The primary and secondary cooling cyclones, and air meal separators which are a part of the process, are the major pollution sources. Control equipment such as multitube collectors and bag filters has been used as auxiliary dust separators on the air meal separator. However, the oil additive that is sometimes used in the dehydrating process causes clogging of bag filters. Other methods suitable for control of effluents discharged to the atmosphere include incineration and electrical precipitation, but in general these are more costly than bag filter units.[7]

8.5 COTTON GINS

Modern cotton ginning installations using pneumatic conveying equipment, air blast equipment, and seed cotton conditioning equipment have increased the output of normal ginning operations and improved cotton fiber quality. This gain in output has been accompanied by a major increase in the volume of air bearing lint and dust discharged to the atmosphere. Although the discharge of waste material to the atmosphere from an individual cotton ginning operation generally results in only a local air pollution problem, the number of such establishments and the gradual urban encroachment into the areas of ginning operations is sufficient to warrant consideration of their overall pollution potential.[8]

Figure 8-2 illustrates a flow diagram for a cotton gin used by the Department of Agriculture to study particulate emissions from ginning operations. This particular operation is considered to be representative of ginning operations in general.[8] The flow diagram indicates the following major sources of particulate emissions: unloading fan, six-cylinder cleaner, stick and bur machine, gin stand, separator No. 2, seven-cylinder cleaner, separator No. 3, and the condenser. The unloading fan supplies the air for the transfer of cotton from the storage bins or from a wagon to the first separator. These wastes are carried to the dust house by the

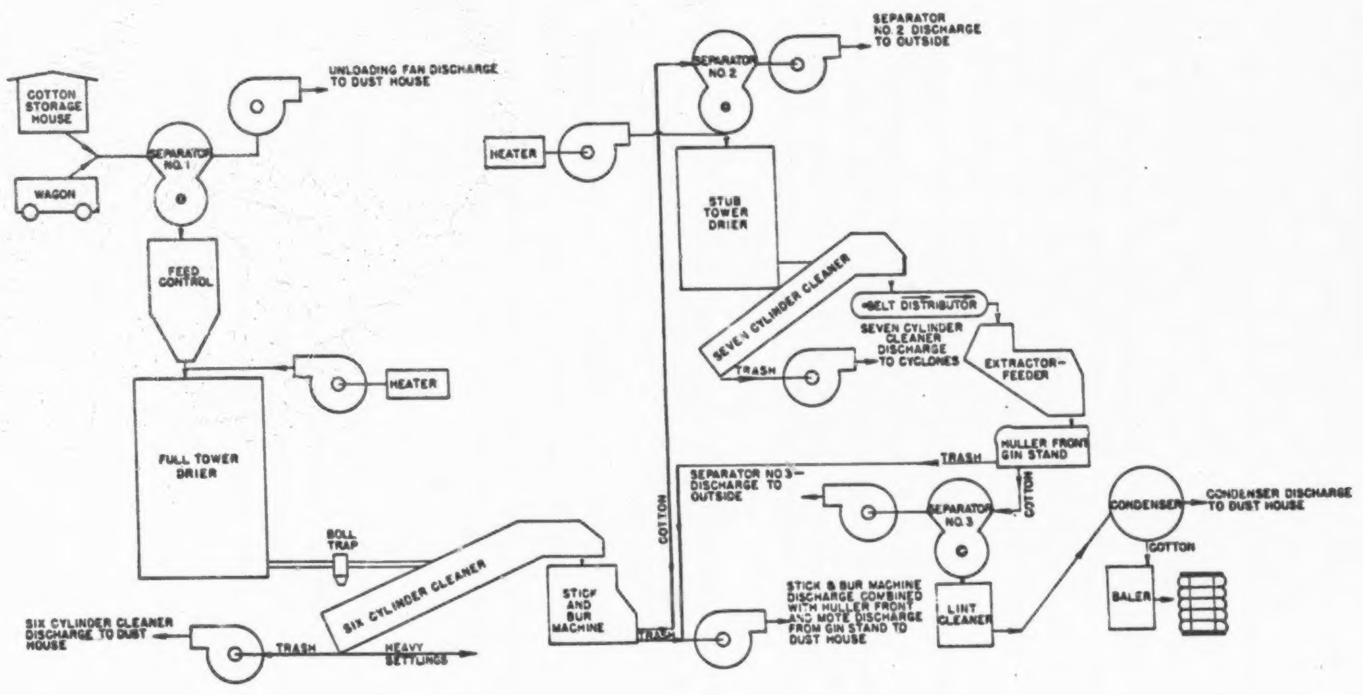
COTTON STORAGE HOUSE
WAGON
SEPARATOR NO. 1
UNLOADING FAN DISCHARGE TO DUST HOUSE
FEED CONTROL
HEATER
FULL TOWER DRIER
BOLL TRAP
SIX CYLINDER CLEANER DISCHARGE TO DUST HOUSE
TRASH
HEAVY SETTLINGS
SIX CYLINDER CLEANER
STICK AND BUR MACHINE
TRASH
HEATER
COTTON
SEPARATOR NO. 2
SEPARATOR NO. 2 DISCHARGE TO OUTSIDE
STUB TOWER DRIER
SEVEN CYLINDER CLEANER
TRASH
BELT DISTRIBUTOR
SEVEN CYLINDER CLEANER DISCHARGE TO CYCLONES
EXTRACTOR-FEEDER
HULLER FRONT GIN STAND
TRASH
SEPARATOR NO 3-DISCHARGE TO OUTSIDE
SEPARATOR NO. 3
COTTON
STICK & BUR MACHINE DISCHARGE COMBINED WITH HULLER FRONT AND MOTE DISCHARGE FROM GIN STAND TO DUST HOUSE
LINT CLEANER
CONDENSER
CONDENSER DISCHARGE TO DUST HOUSE
COTTON
BALER

Figure 8-2 - Flow Diagram of U. S. Department of Agriculture Cotton Gin, Stoneville, Mississippi[8]

moving air stream and consist mostly of sand, dirt, and other fine materials. The dust house is a tall structure open at top and sometimes also open at bottom and it acts as a settling chamber or elutriator.

The cotton then passes from the first separator onto the feed control, into the tower dryer, through a boll trap, and then to the six-cylinder cleaner which opens and cleans the boll cotton. The waste discharge from the six-cylinder cleaner is carried to the dust house by a moving air stream and consists of fine particles of leaf trash, dirt, sand, stems, and small sticks. From the cleaner the cotton is moved to the stick and bur machine which removes burs, sticks and stems, together with fine trash not removed by the cylinder cleaner. The discharge duct from the stick and bur machine joins with the air discharge duct from the gin stand. Wastes from these sources are carried to the dust house.

From the stick and bur machine the cotton passes to a second separator, then to a stub tower dryer, and then to a seven-cylinder cleaner. The discharge from the second separator is emitted directly to the atmosphere outside the building. These wastes, carried through the separator, consisted mainly of fine particles of leaf trash, dirt, sand and stems.

The waste discharge from the seven-cylinder cleaner is carried to cyclones. These wastes consist mainly of sand, trash, and dirt.

The seed cotton then passes from the seven-cylinder cleaner on a belt distributor to the extractor-feeder and then to the huller front gin stand. The trash from the gin stand (burs, sticks, stems, motes, and sand)is combined with the waste discharge from the stick and bur machine and blown to the dust house.

From the gin stand the cotton is transferred first to a separator which removes fine leaf particles, motes, dust, and sticks, which are discharged directly to the atmosphere outside the building. The cotton next travels to the lint cleaner, and then to the condenser which discharges sand and dirt to the dust house. From the condenser the cotton goes to the baler and out as a finished product.

8.5.1 Emissions

Data on atmospheric emissions from cotton ginning operations are limited in scope. Reference 8 presents data from a study conducted at the Cotton Ginning Laboratory, Agricultural Research Service, U.S.D.A., Stoneville, Mississippi. This operation was considered to be representative of ginning operations in general, and the cotton harvested by both machine- and hand-picked methods and processed during testing was representative of the cotton from the test area.[8]

The ginning operation and subsequent incineration of the waste can release pesticide residues, bacteria, benzene-soluble organic matter, and arsenic compounds to the atmosphere. Paganini[9] reported data on particulate matter collected upwind and downwind from cotton gins.

The bacteria and fungi counts in samples taken upwind were 88 to 100 and 33 to 70/m^3 of air, respectively, when collected on nutrient agar. The counts in samples taken downwind ranged from 172 to 1,752 and 19 to 129/m^3 of air, respectively.

Smoke emitted from incineration of cotton gin waste was found to contain significant amounts of benzene-soluble organic matter and arsenic, and to reduce visibility to such an extent at times in some locations that driving was hazardous on the highway.

Emission rates from cotton ginning are summarized in Table 8-2. Particulate emissions currently total 45,000 tons/year.

8.5.2 Effluent Characteristics

Available data on the chemical and physical properties of effluents from cotton ginning operations are summarized in Table 8-3. The concentrations of arsenic, pesticides, and defoliant in effluents from various phases of the ginning operation generally exceed many times the concentration found in natural ambient air.

8.5.3 Control Practices and Equipment

The ginning operations employ small-diameter cyclones for removal of dust, trash, fibers, etc. The small-diameter cyclone that came into widespread use several years ago has proved effective. It creates more static pressure but its higher efficiency makes up for this increased cost of operation.[10]

It is standard practice to place all but one of the cyclones in a battery beside the gin building. They all discharge into a screw conveyor that has a dust-tight cover. The conveyor in turn discharges trash through a conventional dropper into an air line that conveys it to a bur house or incinerator. The air from one of the gin's fans, preferably the fan handling the lint cleaner's trash, is used for this purpose, because this fibrous material has a tendency to choke a conveyor. In some areas the dust coming from the exhaust of the cyclones may be objectionable and further filtering may be necessary. This can probably best be accomplished using an in-line filter or other commercial type filter.[10]

A guide in selecting the proper cyclone arrangement and dimensions for normal gin plant installations is given in Reference 2. This guide also describes the sizing of lint fly catchers and in-line air filters. The in-line air filters have proven to be over 99% efficient in the collection of trash and fly (see Figure 8-3).[11]

Another source of emissions is the incinerators at cotton gins which have been in use for many years for the purpose of burning burs, sticks, stems, leaf trash, and motes.[11]

The concentration of particulates which exit the cyclone collector on a seven-cylinder cleaner has been found to be as low as 0.005 grains/scf for a 34-in. diameter high-efficiency cyclone.[12]

8.5.3.1 Control Equipment: The methods available to the ginner for removal of particulate matter and lint fly from this discharge air are limited by economic and practical reasons to the following, listed in order of increasing capital investment.[13]

8.5.3.1.1 Gravity or settling chamber: Air is introduced into a large enclosure to lose velocity and drop out particles prior to discharge of air. The condenser exhaust "dog house" is an example. Condenser exhaust air introduced into large chambers with screened sides has been observed to operate satisfactorily where 14 x 18 mesh screen wire was employed. It is not believed that settling chambers alone are feasible for use on air exhausts other than from the condensers because of the greater dust loads from other gin exhausts.[13]

In some instances, use of settling to remove larger particles prior to passage of air through a cyclone collector unit will reduce the load on the cyclone and increase its collection efficiency.

8.5.3.1.2 Cyclones: The cyclone collector is widely used in cotton gin emissions. Its first cost compares favorably with other types of collectors. It is simple, rugged, has a low operating cost, and requires little attention. The cyclone will operate very well under surprisingly wide limits. However, careful sizing must be done to avoid excessive pressure drop and at the same time provide for the most efficient collection of dust and lint.

The smaller the cyclone, the greater the efficiency; therefore, it is recommended that multiple, parallel units be used rather than one larger cyclone. Sizing of cyclones is described and illustrated in References 11 and 13.

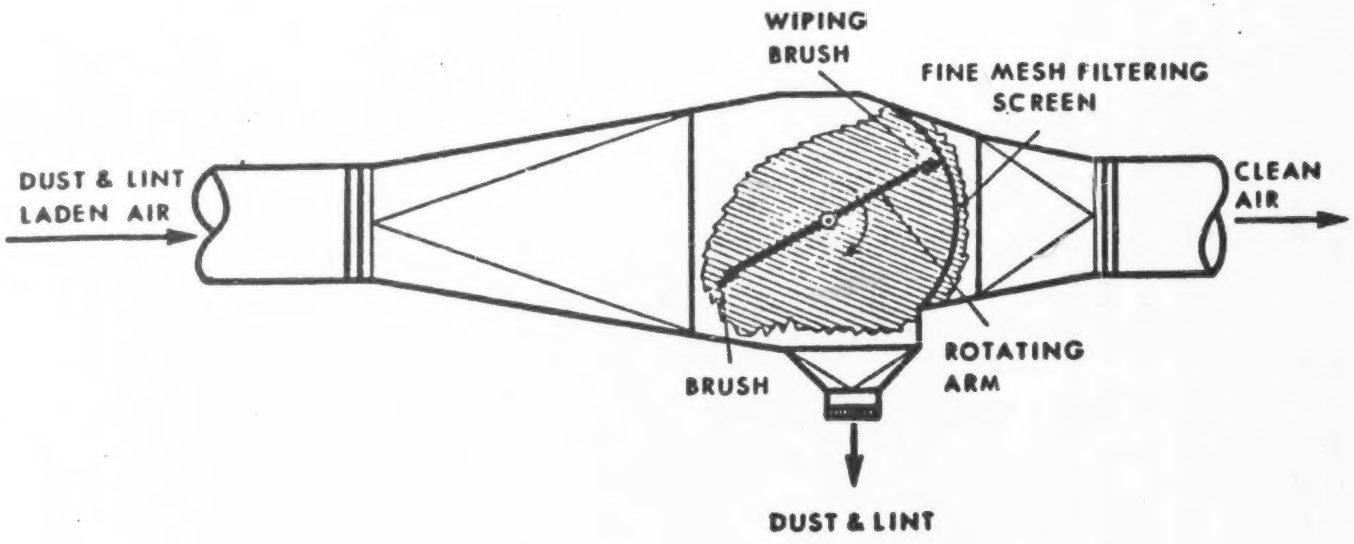

Figure 8-3 - In-Line Air Filter - Cotton Gin[11]

8.5.3.1.3 Scrubbers: The use of settling chambers with adequate water sprays or tanks has been observed to operate very well in some instances. However, care must be taken that water disposal does not become a problem.[13]

8.5.3.1.4 Lint fly catchers and filters: All of the lint fly units permit a build-up of lint on the screen and this provides additional filtration. Each of these units must be of sufficient size and properly installed and maintained to prevent back pressure build-up on the system they serve.

Cloth filters are efficient collection devices and various commercial units are available. The cost of proper installation of filter units is high because sufficient particle arrestment capacity must be provided to allow shutdown of portions of it at intervals for cleaning.[13]

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CHAPTER 9

IRON AND STEEL INDUSTRY

9.1 INTRODUCTION

The manufacture of iron and steel involves many different processes until semifinished products are available for sale or further use. Some of the processes produce large quantities of particulates and gaseous emissions, while other processes are relatively free of air pollution problems. The pyrometallurgical processes inherent in the iron and steel manufacturing processes emit a very fine-size particulate material.

The major sources of particulate air pollution are: sintering plants, coke-oven plants, blast-furnace operations, steel-making furnaces (especially those using large amounts of oxygen for steel making), and materials-handling operations.

The manufacturing process, particulate emission sources, emission rates of individual sources, chemical and physical properties of the effluents, control practices, and control equipment are discussed in the following sections.

9.2 IRON AND STEEL MANUFACTURING

A composite flow diagram for an integrated iron and steel plant is shown in Figure 9-1. The diversity of the operations and the myriad emission sources are apparent. A compilation of potential emission sources is presented in Table 9-1. The numbering sequence corresponds to that shown in Figure 9-1.

A detailed discussion of manufacturing processes has been presented in a recent NAPCA report and those seeking more information on the individual processes are referred to it.1/ Emission rates from individual sources are discussed in the following sections.

9.3 EMISSION RATES FROM IRON AND STEEL MANUFACTURE

9.3.1 Sinter Machines

Sintering machines generally accept and process a wide variety of feeds and produce a considerable quantity of emissions of variable quantity and nature.1/ Emissions from sinter plants vary widely in quantity

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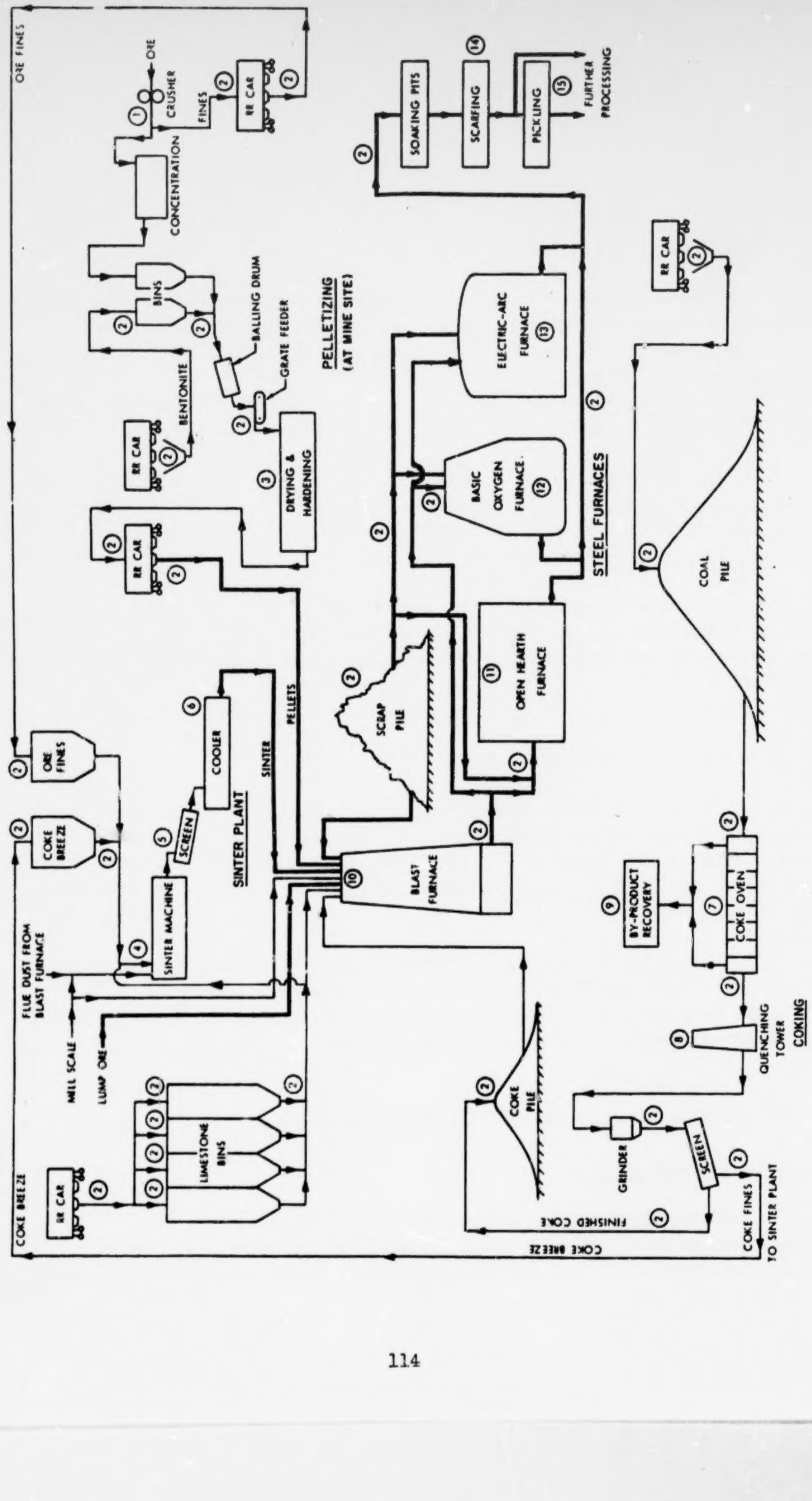

Figure 9-1 - A Composite Flow Diagram for a Steel Plant

TABLE 9-1

POTENTIAL PARTICULATE POLLUTANT EMISSION SOURCES IN IRON AND STEEL MANUFACTURING

Source		Particulates
1. Ore crushing		Ore, coal and limestone dust
2. Materials handling and stockpiles		Ore, coal and limestone dust
3. Pelletizing dryer		Ore and coal dust
4. Sinter machine		Iron oxides, calcite, iron calcium silicates, and quartz
(a) Windbox		
(b) Discharge end		
5. Sinter machine screen		
6. Sinter cooler		
7. Coke ovens		Coal, smoke, and coke
(a) Charging		
(b) Coking (no by-product recovery)		
8. Coke quenching tower		
9. Coke by-product recovery		Hydrocarbon vapors and/or mists
10. Blast furnace		Iron oxides, coke, and limestone
(a) Charge		
(b) Heat		
(c) Tap		Kish
Steel-Making Furnaces		
11. Open hearth		Iron oxides, lime, kish, silica
12. Basic oxygen		
13. Electric-arc		
(a) Charge	Particulate emitted from each furnace during these stages	
(b) Heat		
(c) Tap		
14. Scarfing		Iron oxide
15. Pickling		H_2SO_4, HCl fumes, Water-oil mist

and particle size and depend upon, among other things, raw mix composition, types of machines, and exhaust-fan characteristics.

Sinter machine emission sources can be divided into two categories: (a) windbox emissions, and (b) discharge-end emissions. Windbox emission dusts are mainly generated early in the sintering process, and again later, when the flame front has reached the bottom of the bed. Emissions from the discharge end parallel those of the windbox on a basis of pounds emitted per ton of sinter. However, grain loadings are higher at the discharge end.

9.3.2 Coke Ovens

Metallurgical coke is the major fuel and reducing agent used in the production of blast furnace hot metal, and will probably be the major fuel and reductant for many years in the future. Beehive coke is still made to a limited extent, but 99% of coke production utilizes the by-product coke oven.

During the manufacture of coke and during the processing of coke by-products, emissions are generated in several locations and operations: (1) coal handling; (2) oven charging; (3) oven operation, pushing and quenching; (4) coke handling; and (5) by-product processing. Most of the particulates escape during the charging and discharging (i.e., pushing) operations. At the end of the coking cycle, the incandescent coke is transferred from the oven into a quenching car by a hydraulic ram. The quantity of smoke rising from the mass during the period required to transport the coke to the quenching station is dependent upon the degree of coking. Incompletely carbonized coke gives rise to considerable quantities of smoke; conversely, thoroughly carbonized coke gives rise to very little smoke.2/

9.3.3 Blast Furnace

The blast furnace is one of the largest chemical reactors used by industry. It acts as a counter-current reactor in which solid materials descend by gravity from the top and react with gases generated near the bottom.

Iron ore, fluxes, and coke are charged into the top of the furnace through a succession of two of three seals that serve to limit leakage of gas at this point. Preheated air (sometimes augmented with oil, gas, oxygen, or steam) is forced through ports (tuyeres) arranged radially near the bottom of the furnace and just above the hearth. The incoming air and admixed additives react between themselves and with the hot coke to generate a reducing gas rich in hydrogen and carbon monoxide, at a flame temperature of up to 3500°F. The hot reducing gases liberate some of their heat to melt the iron and slag, then continue upward to carry energy and chemical potential to the unreduced ore in the upper part of the furnace. Molten iron and slag drip down into the hearth and are tapped intermittently through special ports.[2]

Two emissions come from the top of a blast furnace: top gas and the dust which it entrains. The top gas is a mixture mainly of steam, nitrogen, carbon monoxide, and carbon dioxide. On a dry basis, this gas may average 25 to 30 vol. % carbon monoxide. Emissions to the atmosphere occur from leakage around hoppers and seals. Top gas may leak from openings such as ports for rods used to determine the height of the charge materials inside the furnace. Dust entrained in the top gas is a result of the abrasion sustained by the burden materials during charging and during the initial stages of passage down the blast furnace. It is possible to minimize particulate emissions by choice of raw materials and sound operating practices, and thereby to reduce the load on the dust-cleaning system.[1]

9.3.4 Steel-Making Furnaces

9.3.4.1 Open-Hearth Furnaces: Particulate and gaseous emissions from the open-hearth process originate from (1) the physical action of the flame on the charged materials and the resulting pickup of fines, (2) the chemical reactions in the bath, (3) the agitation of the bath, and (4) the combustion of fuel.[1,3,4] The amount of dust generated during the open-hearth process varies according to the different stages of the process and according to operating practices. Oxygen lancing produces more particulate emissions than open-hearth practice without lancing.

A typical heat is composed of 60% hot metal and 40% scrap, and usually proceeds as follows: the bottom of the furnace is first built up with dolomite and the burners are fired. The furnace is then charged with limestone and steel scrap. The time required for this charging and meltdown of the scrap varies between 2 and 4 hr., depending upon the furnace size and the ratio of hot metal to scrap. The hot metal is added when the scrap is partially melted. Decomposition of the limestone begins when the temperature of the bath increases. The release of carbon dioxide gas from the limestone increases agitation in the bath. After the lime boil has been completed and the lime solution is in the slag, the rate of decarbonization increases. When gaseous oxygen is used for decarbonization, the flow of oxygen is started after the addition of hot metal.[2]

Fume generation from the open hearth occurs during the charging, melting, and refining phase. Emission rates vary considerably during the process cycle, and quite likely vary from cycle to cycle depending on the quality of the scrap charged into the furnace. For the furnace utilizing oxygen-lancing (i.e., impinging stream of high-velocity oxygen), Reference 5 gives a dust loading of 0.78 grain/scf at 60,000 scfm gas flow at meltdown, 1.9 grains/scf at 64,000 scfm at hot metal addition, 2.70 grains/scf at 66,000 scfm at the lime boil, up to 5 grains/scf during oxygen lancing and 0.21 grain/scf at 64,000 scfm during refining.

9.3.4.2 Basic Oxygen Furnaces: Basic oxygen furnaces (BOF) are becoming the principal method of making steel in the U. S. In basic oxygen steel-making, the need for a large-surface bath (such as is required in open-hearth steel-making) is overcome by forcing a jet of high-purity oxygen below the surface of the metal. The jet also provides violent agitation, and therefore increases the area of the slag-metal interface. The BOF process is exothermic to the extent that up to 30% (or more) of steel scrap can be melted, using as fuel only the carbon and other metalloids dissolved in the metal. No conventional fuel is added. In terms of emissions, the sulfur dioxide and unburned hydrocarbons associated with open hearths are non-existent with BOF furnaces.1/

In the initial stage of basic oxygen steel-making, the charging of carbon-saturated hot metal upon cold scrap results in a release of kish as the molten iron is rapidly cooled. Only a part of this kish is contained by the furnace vessel. The initiation of oxygen blowing is marked briefly by a heavy dark-brown smoke (caused by the direct burning of iron). This smoke persists until the metalloids begin to oxidize and refining begins.

As most of the metalloids become oxidized, the oxidation of carbon increases to consume the rest of the oxygen blown, and the volume of gas leaving the furnace mouth increases noticeably. An excess of air often is permitted to mix with the exhaust gases as they pass into the fume-exhaust system. The use of excess air is a safety precaution to prevent the existence of a high carbon monoxide content in the flue system, and eliminate a possible explosion hazard.

During the oxidation of carbon, the fuming appears to be limited to iron dust either from iron vaporized from the bath or as iron droplets ejected by the carbon monoxide rising from the molten bath. Factors that determine the amount of fumes generated during the blowing process include the type of oxygen lance used, the velocity of the oxygen, the carbon content of the iron, and the temperature of the iron.1/

9.3.4.3 Electric-Arc Furnaces: Emissions generated during electric furnace steel-making originate from the physical nature of scrap used, scrap cleanliness, the nature of the melting operation, and oxygen lancing. Fume and particulate are emitted from the furnace during the charging and refining operations. During the charging period, the top of the furnace is opened to charge cold metal. Exposure of the cold charge to high temperatures within the furnace results in the generation of large quantities of fume. Fume emissions can be affected by the sequence of charge additions to the furnace.

The method of refining also has a pronounced effect on fume emission. An oxygen lance leads to higher fume release rates because of the breaking of the slag film and because of the high temperatures reached during the lancing stage.

The nature of the material charged also has a marked influence on emission rates. Thin steel scrap will oxidize easily, and result in heavy fuming and a high metal loss during melting in electric-arc furnaces. Dirty scrap is a major source of emissions. Electric furnaces melting dirty scrap can generate as much dust as an electric furnace with oxygen lancing.[1]

9.3.5 Scarfing Operations

Before steel can be rolled, surface defects in the bloom, ingot, and billets must be removed. The scarfing operation removes these defects. Jets of oxygen are directed at the surface of the steel, which is maintained at high temperature, causing localized melting and subsequent oxidation of the steel.

9.3.6 Summary of Emission Rates From Iron and Steel Manufacture

Table 9-2 summarizes the emission rates from the various operations that comprise the manufacturing cycle for iron and steel. Particulate emissions currently total about 1.4 x 10^6 tons/year. Furnace operations, sinter machines, coke manufacture, and material handling operations are the dominant sources of particulate emissions. Emissions from the material handling operations were calculated using engineering estimates of average efficiency of control devices and degree of application of control.

9.4 CHARACTERISTICS OF EMISSIONS FROM IRON AND STEEL MANUFACTURE

Table 9-3 presents a summary of the chemical and physical properties of the effluents from the various processes involved in the manufacture of iron and steel. The nature of the emissions is highly variable. The pyrometallurgical steps present distinct control problems because of the generation of very fine particulate matter. Emissions from open-hearth, basic-oxygen, and electric-arc furnaces may consist entirely of submicron metallic fumes and particulates.

The variation in resistivity of open-hearth furnace fumes shown in Figures 9-2 to 9-5 gives an indication of the data spread for this type of data. This variation is to be expected because of the different compositions of the heats, especially varying concentrations of limestone. Therefore, wherever the resistivity exceeds a value of about 2 x 10^{10} ohm-cm, in-situ measurements should be made.

Data on particle shapes, which could not be readily presented in tabular form are detailed in the following paragraphs.

TABLE 9-2

PARTICULATE EMISSIONS IRON AND STEEL INDUSTRY

	Source	Quantity of Material	Emission Factor	Efficiency of Control C_c	Application of Control C_t	Net Control $C_c \cdot C_t$	Emissions (tons/year)
I.	Ore Crushing	82,000,000 tons of iron ore	2 lb/ton of ore	0.0	0.0	0.0	82,000
II.	Materials Handling	131,000,000 tons of steel	10 lb/ton of steel	0.90	0.35	0.32	446,000
	A. Loading-Unloading, Freight Cars, Barges, Ore Boats		-				
	1. Ore and ore fines		-	-	-	-	-
	2. Clay (bentonite)		-	-	-	-	-
	3. Limestone		-	-	-	-	-
	4. Coal		-	-	-	-	-
	5. Scrap metal		-			-	
	B. Conveyors						
	1. Transfer points		-	-	-	-	-
	2. Discharge to bins stockpiles		-	-	-	-	-
	C. Elevators						
	1. Boots		-	-	-	-	-
	2. Heads		-	-	-	-	-
III.	Pellet Plant	50,000,000 tons of pellets					80,000
	A. Grate Feeder		-	-	-	-	-
	B. Dryer		-	-	-	-	-
	C. Kiln		-	-	-	-	-
IV.	Sinter Plant	51,000,000 tons of sinter					
	A. Sintering Process		20 lb/ton sinter	0.90	1.0	0.90	51,000
	B. Crushing, Screening, Cooling		22 lb/ton sinter	0.90	1.0	0.90	56,000
V.	Coke Manufacture						
	A. Ovens						
	1. Beehive	775,000 tons of coke - 1,300,000 tons of coal	200 lb/ton of coal	0.00	0.00	0.00	130,000
	a. Charging		-	-	-	-	-
	b. Coking		-	-	-	-	-
	c. Pushing		0.08 lb/ton of coal	-	-	-	-
	2. By-Product	63,700,000 tons of coke - 90,000,000 tons of coal	2 lb/ton of coal	0.00	0.00	0.00	90,000
	a. Charging		-	-	-	-	-
	b. Coking		-	-	-	-	-
	c. Pushing		0.08 lb/ton of coal[a]	-	-	-	4,000
	B. Quenching Tower		0.38 lb/ton of coal[a]	-	-	-	17,000
	C. Grinder		-	-	-	-	-
	D. Screen		-	-	-	-	-
	E. By-Product Recovery Plant		-	-	-	-	-

TABLE 9-2 (Concluded)

Source	Quantity of Material	Emission Factor	Efficiency of Control C_c	Application of Control C_t	Net Control $C_c \cdot C_t$	Emissions (tons/year)
VI. Blast Furnaces	88,800,00 tons of pig iron					
A. Charge		-	-	-	-	-
B. Heat		-	-	-	-	-
C. Tap		-	-	-	-	-
		130 lb/ton of pig iron	0.99	1.00	0.99	58,000
VII. Steel Furnaces						
A. Open Hearth	65,800,000 tons of steel					
1. No oxygen lancing						
a. Charge		-	-	-	-	-
b. Heat		-	-	-	-	-
c. Tap		-	-	-	-	-
		8 lb/ton of steel	-	-	-	-
2. Oxygen lancing						
a. Charge		-	-	-	-	-
b. Heat		-	-	-	-	-
c. Tap		-	-	-	-	-
		21 lb/ton of steel	-	-	-	-
	Average for open hearth	17 lb/ton of steel[b]	0.97	0.41	0.40	337,000
B. Basic Oxygen (BOF)	48,000,000 tons of steel					
1. Charge		-	-	-	-	-
2. Heat		-	-	-	-	-
3. Tap		-	-	-	-	-
		40 lb/ton of steel	0.99	1.00	0.99	10,000
C. Electric Arc	16,800,000 tons of steel					
1. Charge		-	-	-	-	-
2. Heat		-	-	-	-	-
3. Tap		-	-	-	-	-
		10 lb/ton of steel	0.99	0.79	0.78	18,000
VIII. Scarfing	131,000,000 tons of steel	3 lb/ton scarfed	0.90	0.75	0.68	63,000
IX. Pickling		-	-	-	-	-
		Total for Iron and Steel				1,442,000

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a/ Industrial source.

b/ Emission factor is assumed to be an average for the total heat cycle.

TABLE 9-3

EFFLUENT CHARACTERISTICS - IRON AND STEEL INDUSTRY[+]

A. Particulate (Part I)

Source	Particle Size	Solids Loading	Chemical Composition	Particle Density	Electrical Properties	Moisture Content	Toxicity
Iron and Steel							
a. Sinter Plant							
(1) Windbox	15-45 < 40 9-30 < 20 4-19 < 10 1-10 < 5 Also see Figure 9-2	0.2-3.2	Fe_2O_3: 45-50 SiO_2: 3-15 CaO: 7-25 MgO: 1-10 Al_2O_3: 2-8 C: 0.5-5 S: 0-2.5 Alkali: 0-2 Fluorides		See Figures 9-3, 9-4 and 9-5 for detailed data		
(2) Discharge end	80 < 100, 10 < 10 (one sample)	1-5			See Table 9-4 for data		
b. Coke Oven							
(1) Quench tower	95-97 > 47	0.05-0.1	Coke balls, coal dust, pyrolytic carbon				
(2) Oven charging		1-15	Coal dust				
c. Blast Furnace	Highly variable 15-90 < 74	4-30 7-10 (avg.)	Fe: 36-50 FeO: 12-47 SiO_2: 8-30 Al_2O_3: 2-15 MgO: 0.2-5 C: 3.5-15 CaO: 3.8-28 Mn: 0.5-1.0 P: 0.03-0.2 S: 0.2-0.4	3.4			
d. Open-Hearth Furnace (No oxygen lance)							
*(1) Charge to hot metal		0.56					
*(2) Hot metal to lime up		0.61					
*(3) Lime up to tap		0.18					
*(4) Tap to charge		0.11					
**(5) Composite for heat	50 < 5 Electron microscope 0.01-0.5 Mean count size: 0.03; Mass median: 0.65	0.1-3.5 (dependent upon stage of heat) avg. for heat, 0.4	Fe_2O_3: 85-90 Small amounts of other metallic oxides reflecting charge composition SiO_2: 0.9-1.6 Al_2O_3: 0.5-0.7 CaO: 0.85-1.0 MnO: 0.6 P_2O_5: 0.5-1.2 S: 0.4-1.0 Loss on ignition: 1.1 Fluorides	5.0	See Figures 9-6 - 9-10 for detailed data		

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* Data from one plant only.

** Data from several plants.

[+] See Coding Key, Table 5-1, Chapter 5, page 45, for units for individual effluent properties.

TABLE 9 3 (Continued)

A. Particulate (Part I) (Continued)

Source	Particle Size	Solids Loading	Chemical Composition	Particle Density	Electrical Properties	Moisture Content	Toxicity
d. Open-Hearth Furnace (oxygen lance)(Concluded)							
***(1) Charge to hot metal		0.25-0.78					
***(2) Hot metal to lime up		0.45-1.90					
***(3) Lime up to tap		0.8-2.7					
***(4) Tap to charge		0.21-0.87					
**(5) Composite for heat	Variable, dependent on stage of heat a. Lime boil 45 < 2 75 < 5, 92 < 10 b. Composite 20 < 2 45 < 5 69 < 10 Number count: ~ 100 < 0.1	0.2-7.0 (dependent on stage of heat) Avg. for heat: 1.5	Fe_2O_3: 80-90 FeO: 0.3-3.2 SiO_2: 0.4-2.0 Al_2O_3: 0.2-0.7 CaO: 0.6-1.9 MnO: 0.3-1.0 P_2O_5: 0.5-1.5 MgO: 0.4-1.1 S: 0.4-3.0	5.0-5.2	See Figures 9-6 - 9-10 for detailed data		
e. Basic Oxygen Furnace							
(1) Composite for heat	85-95 < 1 Electron micrograph: count median diameter 0.012 Mass median diameter, 0.095 Geometric deviation, 2.3	2-10	Typical composition Fe_2O_3: 90 FeO: 1.5 Mn: 0.4-1.5 SiO_2: 1.3-2.0 Al_2O_3: 0.2 CaO: 3-5 MgO: 0.6-1.1	3.44	See Figures 9-9, 9-10 and 9-11 for detailed data		
(2) Transfer of hot metal from bottle car to charging ladle (KISH)	33 > 149 54 > 74 84 > 10 97 > 1		P_2O_5, C, SiO_2 Fe_2O_3, CaO, MgO, S				
f. Electric-Arc Furnace							
(1) No oxygen lance (composite for heat)	Highly variable, but generally 60 < 5 BAHCO analysis 68 < 5, 84 < 10, 95 < 20, 99 < 40	0.1-2.2	Variable, dependent on nature of charge Fe_2O_3: 19-44 FeO: 4-10 Cr_2O_3: 0-12 SiO_2: 2-9 Al_2O_3: 1-13 CaO: 5-22 MgO: 2-15 MnO: 3-12 ZnO: 0-44 CuO: 0-1 NiO: 0-3 PbO: 0-4 C: 2-4 Alkalies: 1-11 S: 0-1 P: 0-1	3.8-3.9	Apparent resistivity 6×10^5 – 6.6×10^{13} ohm-cm (dependent on chemical composition) Also see Figure 9-9		

*** Data from three plants.

TABLE 9-3 (Continued)

A. Particulate (Part I) (Concluded)

Source	Particle Size	Solids Loading	Chemical Composition	Particle Density	Electrical Properties	Moisture Content	Toxicity
f. Electric-Arc Furnace (Concluded)							
(2) Oxygen lance (composite for heat)		1-10	Similar to no O_2 lance composition	3.9-4.0			
g. Miscellaneous							
(1) Scarfing machine		0.4-4.4 Commonly used values 0.4-0.8	Mostly Fe_2O_3		See Figure 9-9		

A. Particulate (Part II)

Source	Solubility	Wettability	Hygroscopic Characteristics	Flammability or Explosive Limits	Handling Characteristics	Optical Properties
Iron and Steel						
a. Sinter plant	CaO - s. H_2O CaO, SiO_2, Fe_2O_3, Al_2O_3 - s. 10% HCl				Hardness: 3-5 mohs, Abrasive	
b. Blast furnace	CaO - s. H_2O CaO, SiO_2, Al_2O_3 - s. 10% HCl				Abrasive, fluid cohesive, will arch and bridge	
c. Open-hearth	Fe_2O_3 - s. 10% HCl	Difficult to wet			Abrasive, high angle of repose (~ 90 degrees), cohesive and will bridge and arch	
d. Basic-oxygen furnace	Fe_2O_3 - s. 10% HCl	Difficult to wet			Abrasive, high angle of repose (~ 90 degrees), cohesive and will bridge and arch	
e. Electric-arc furnace		Difficult to wet			Abrasive, fluid-cohesive, high angle of repose, will bridge and arch	

B. Carrier Gas

Source	Flow Rate	Temperature	Moisture Content	Chemical Composition	Toxicity	Corrosivity	Odor	Flammability or Explosive Limits
Iron and Steel								
a. Sinter plant								
(1) Windbox	(a) 30-460 (b) 148-230	100-400	2-10	O_2: 10-20 CO_2: 4-10 CO: 0-6 SO_2: 0-0.4 N_2: 64-86 Fluorides	SO_2 - 5 irritant CO - 100			

TABLE 9-3 (Continued)

B. Carrier Gas (Continued)

Source	Flow Rate	Temperature	Moisture Content	Chemical Composition	Toxicity	Corrosivity	Odor	Flammability or Explosive Limits
a. Sinter plant (Concluded)								
(2) Discharge end	(a) 0.03-0.2	100-300						
b. Coke Oven								
(1) Quench tower	Of the order 900 M ft^3 per quench	140-150		Steam, air				
(2) Oven charging	Of the order 2.1 M ft^3 per charge			CO_2 - 2.2 O_2 - 0.8 N_2 - 8.1 CO - 6.3 H_2 - 46.5 CH_4 - 32.1 C_2H_4 - 3.5 C_6H_6 - 0.5				
c. Blast Furnace	(a) 40-140 (b) 60-138	390 at throat 3000 in furnace	9.6 Dew point, 95-122	CO: 21-42 avg. 26 CO_2: 7-19 avg. 18 H_2: 1.7-5.7 avg. 3.1 CH_4: 0.2-3 N_2: 50-60 Traces: S, H_2S, SO_2, O_2	CO - 100 SO_2 - 5 irritant			Explosive due to CO and H_2 content
d. Open-Hearth Furnace (No oxygen lance)								
*(1) Charge to hot metal	(a) 83.5		17.2					
*(2) Hot metal lime up	(a) 75.2		18.5					
*(3) Lime up to tap	(a) 70.7		17.2					
*(4) Tap to charge	(a) 47.6		13.3					
**(5) Composite for heat	(a) 25-100	460-1800 (depending on utilization of waste heat boiler)	7-15	CO_2: 8-9 O_2: 8-9 N_2: balance SO_2: 2-5 ppm SO_3: 100-200 ppm NO_x: 500-800 ppm Fluorides may by emitted due to fluxing agent or fluoride content of ore (0-300 ppm)	SO_2 - 5, irritant HF - 3	Potentially corrosive due to SO_2, SO_3		

TABLE 9-3 (Concluded)

B. Carrier Gas (Concluded)

Source	Flow Rate	Temperature	Moisture Content or Condensable Vapors	Chemical Composition	Toxicity	Corrosivity	Odor	Flammability or Explosive Limits
d. Open-Hearth Furnace (Concluded) (Oxygen lance)								
**(1) Composite for heat	(a) 45-200	400-2000 (depending on utilization of waste heat boiler)	Varies during cycle 13-19 avg. 15	Similar to no O_2 lance composition	SO_2 - 5, irritant HF - 3	Potentially corrosive due to SO_2, SO_3		
e. Basic Oxygen Furnace								
(1) Composite for heat	(a) 35-250	560-3000 (depending on utilization of waste heat boiler)		Before combustion with aspirated air: a. BOF CO_2: 5-16 CO: 74-91 N_2: 3-8 b. Kaldo Process CO_2: 72.3 CO: 22.7 N_2: 4.4 After combustion with aspirated air: a. BOF CO_2: 0.7-13.5 CO: 0-0.3 N_2: 74.5-78.9 O_2: balance				Highly flammable prior to combustion with aspirated air
f. Electric-Arc Furnace (includes both unlanced and lanced furnaces)	(a) 10-100	215-3000 (Dependent on use of cooling techniques)	0.045 lb/lb dry gas (1 sample)	Mainly CO_2, CO, O_2, and N_2 Composition varies with operating practice. For O_2 lance composition varies with time. Typical variation: CO: 8-85 CO_2: 5-15 N_2: 5-85				Flammable due to CO content
g. Miscellaneous								
(1) Scarfing machine	(a) 20-150							

** Data from several plants.

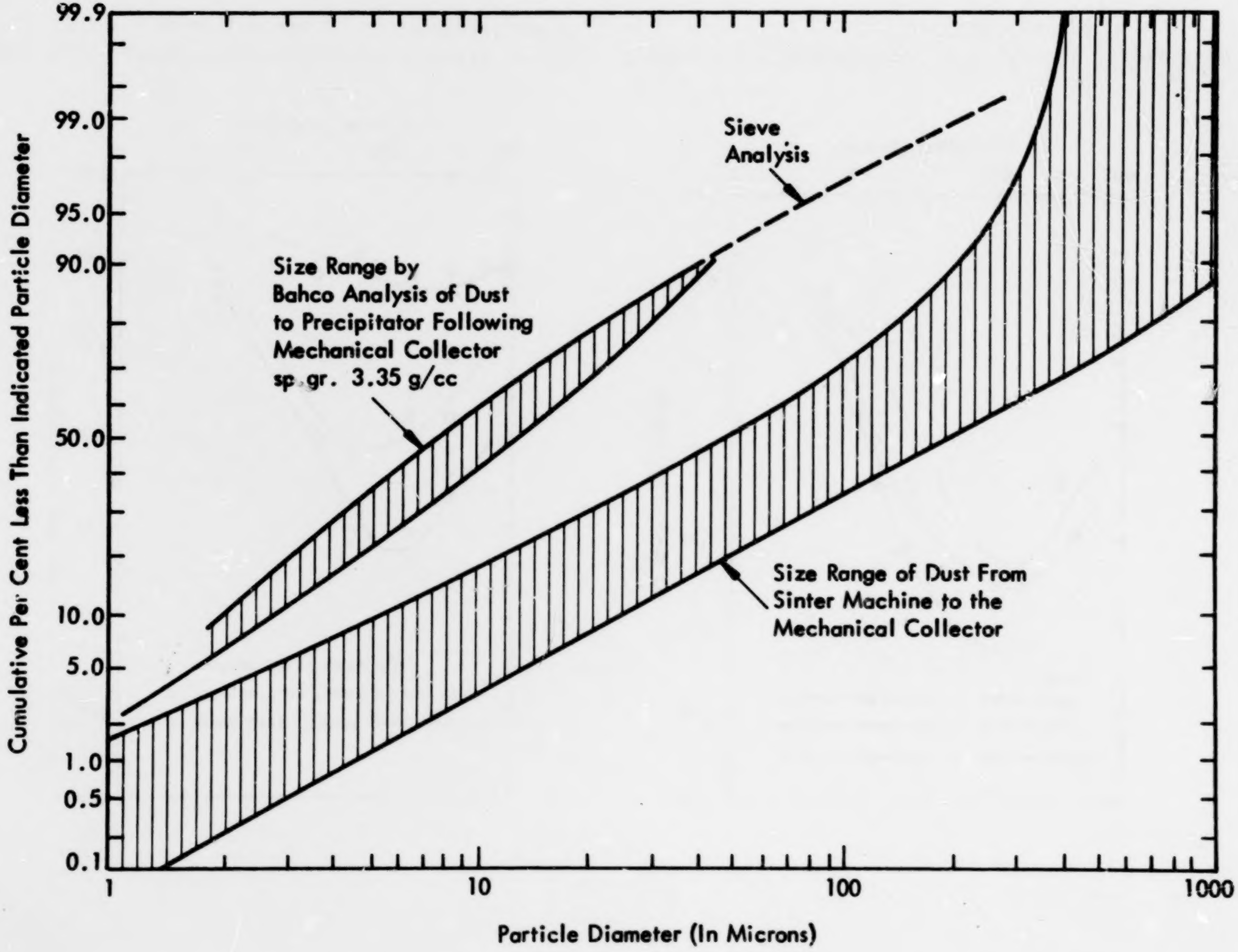


Figure 9-2 - Particle Size Distribtuion by Weight of Sintering Machine Dust[36]

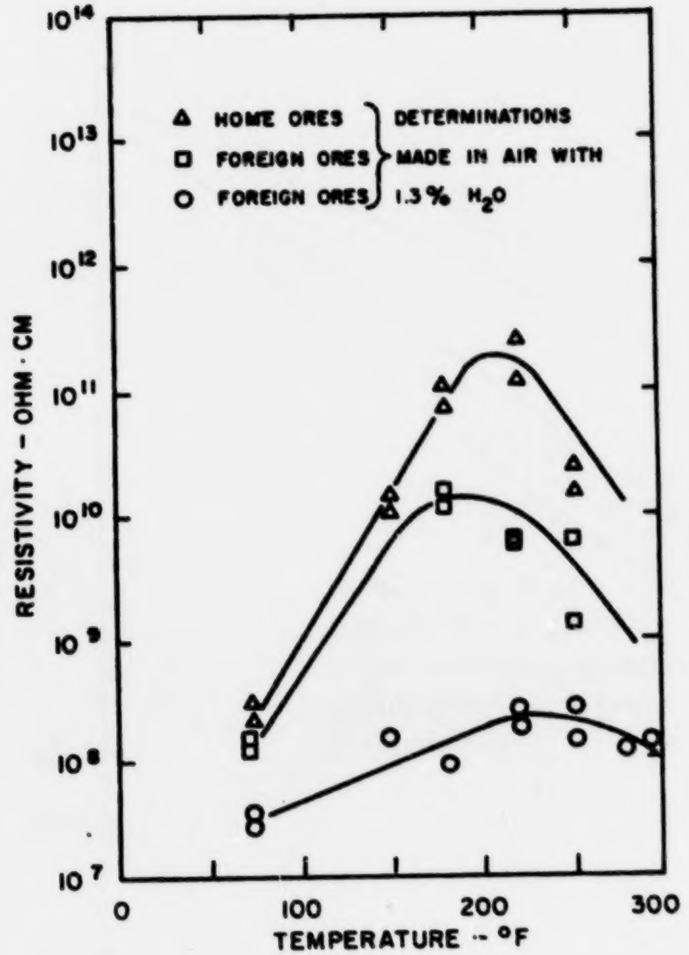


Figure 9-3 - Resistivity of Different Dusts in the Same Atmosphere vs. Temperature[35]

(Sinter Plant)

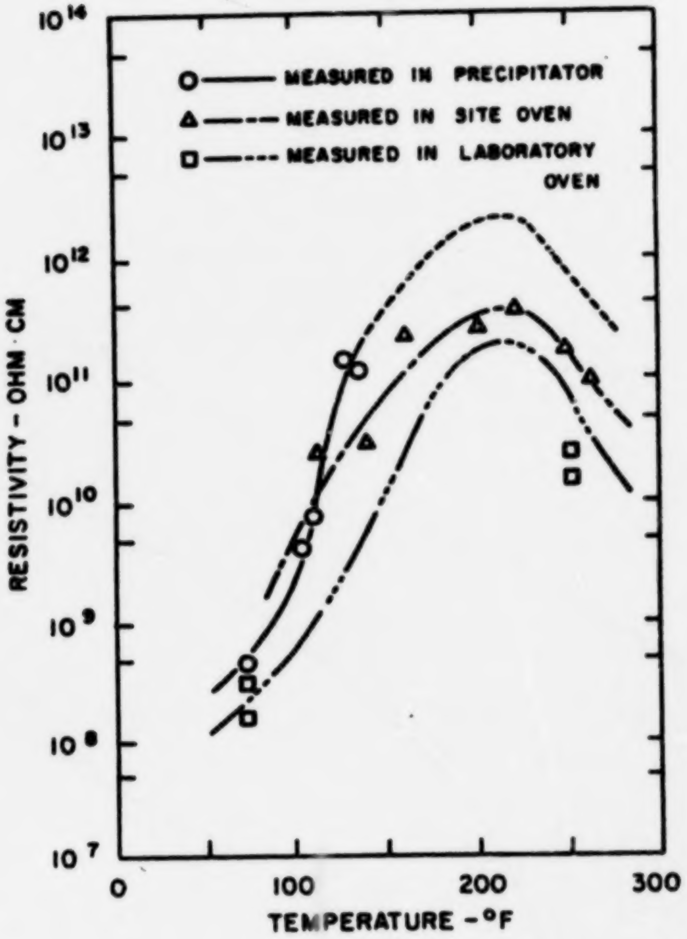
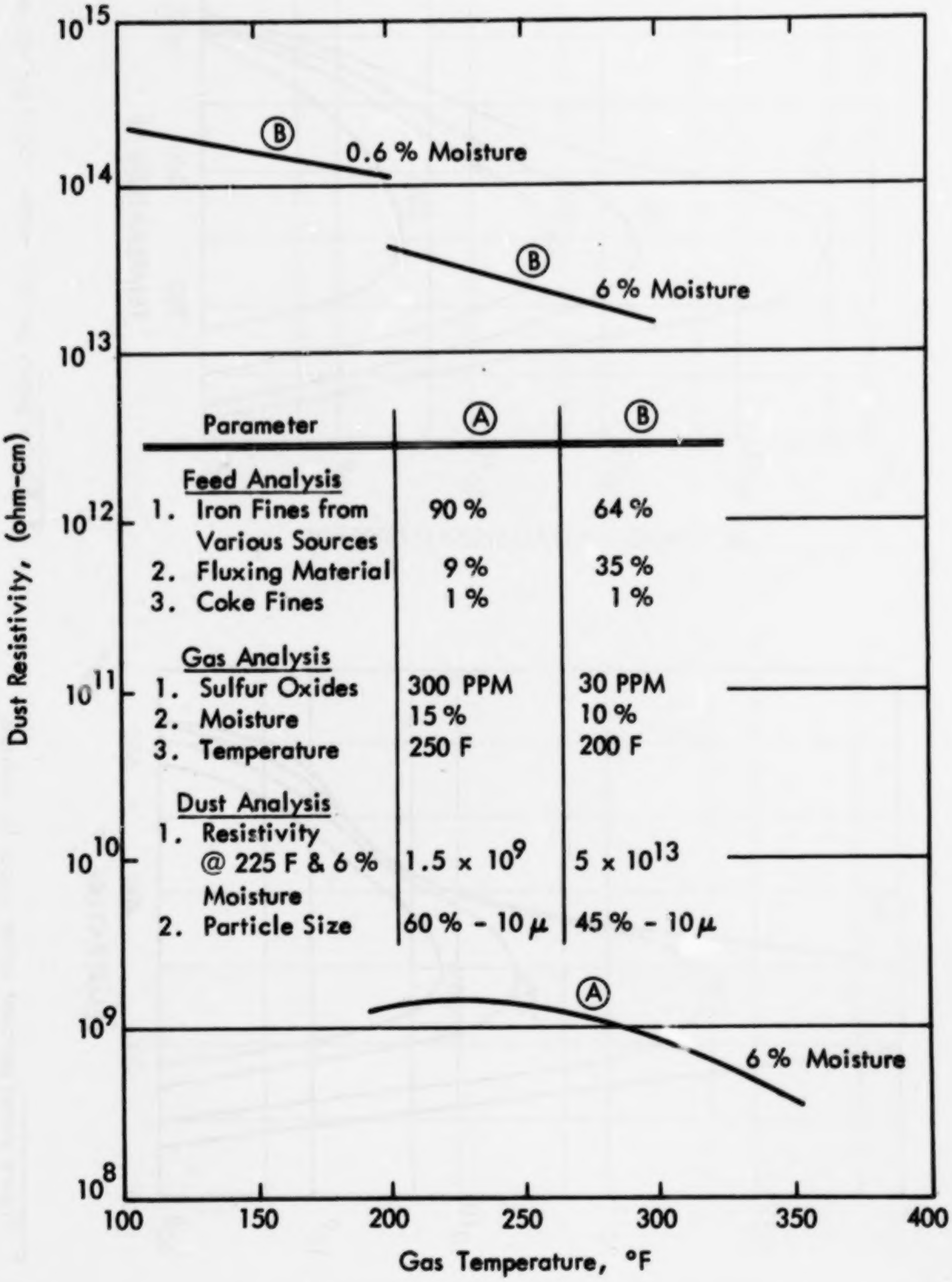


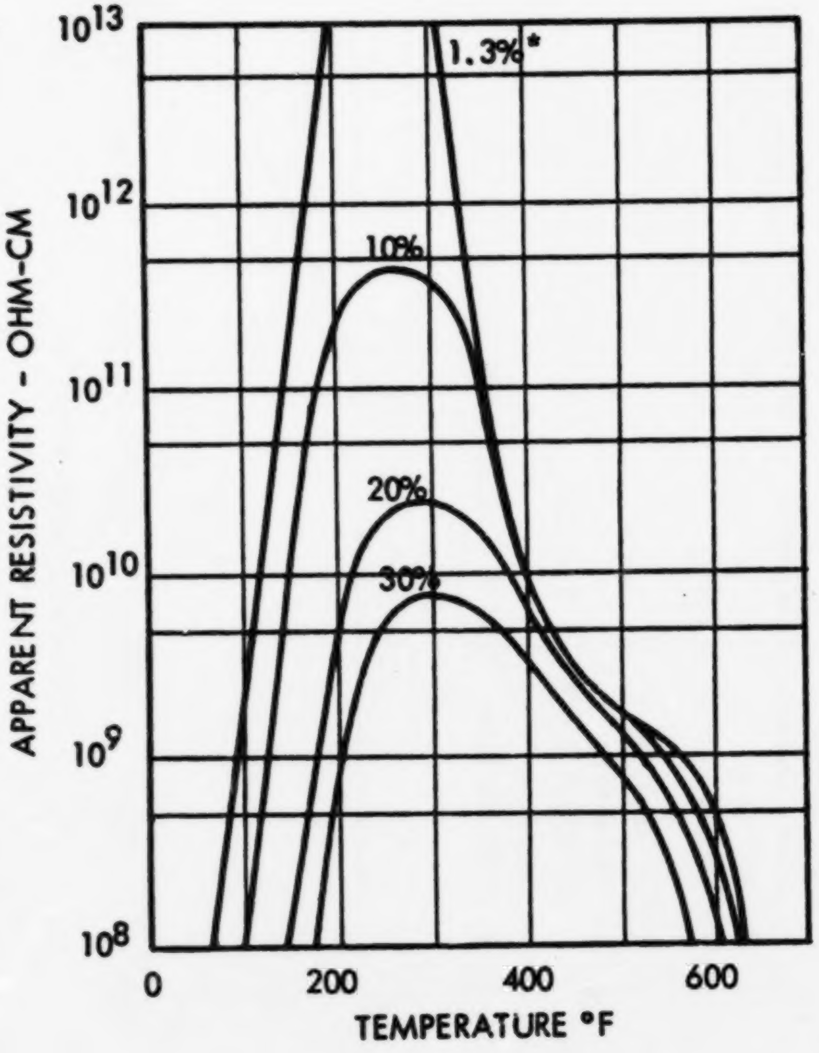
Figure 9-4 - Resistivity in Different Atmospheres vs. Temperature[35]

(Sinter Plant)



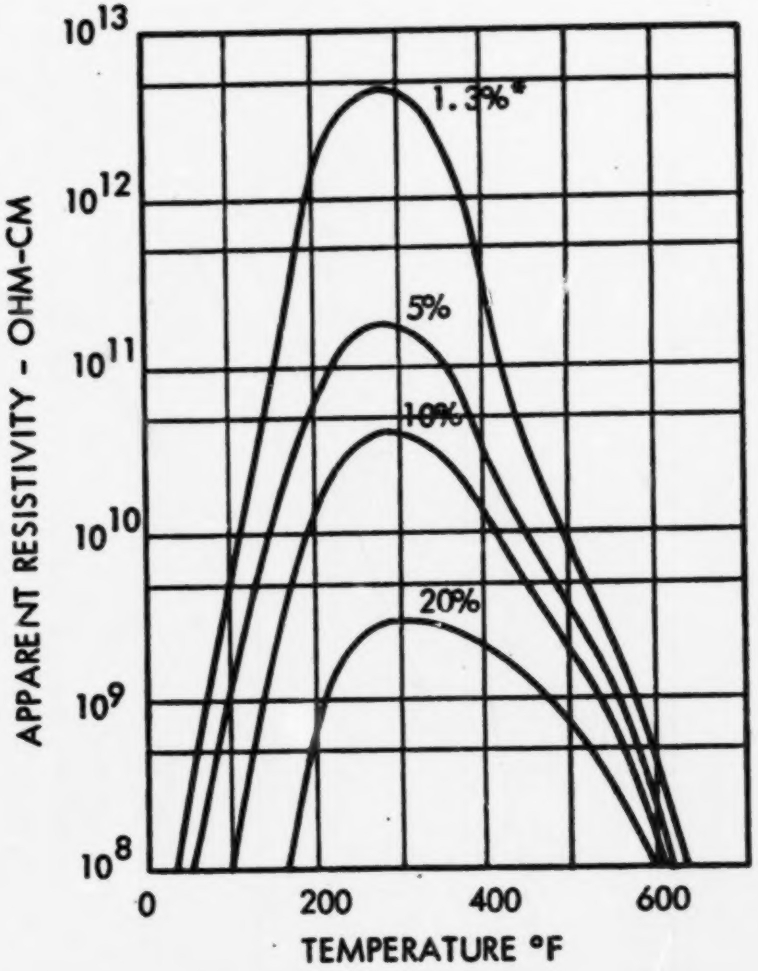
Parameter	Ⓐ	Ⓑ
Feed Analysis		
1. Iron Fines from Various Sources	90 %	64 %
2. Fluxing Material	9 %	35 %
3. Coke Fines	1 %	1 %
Gas Analysis		
1. Sulfur Oxides	300 PPM	30 PPM
2. Moisture	15 %	10 %
3. Temperature	250 F	200 F
Dust Analysis		
1. Resistivity @ 225 F & 6 % Moisture	1.5×10^9	5×10^{13}
2. Particle Size	60 % - 10 μ	45 % - 10 μ

Figure 9-5 - Electrical Resistivity of Sintering Machine Dust[36]



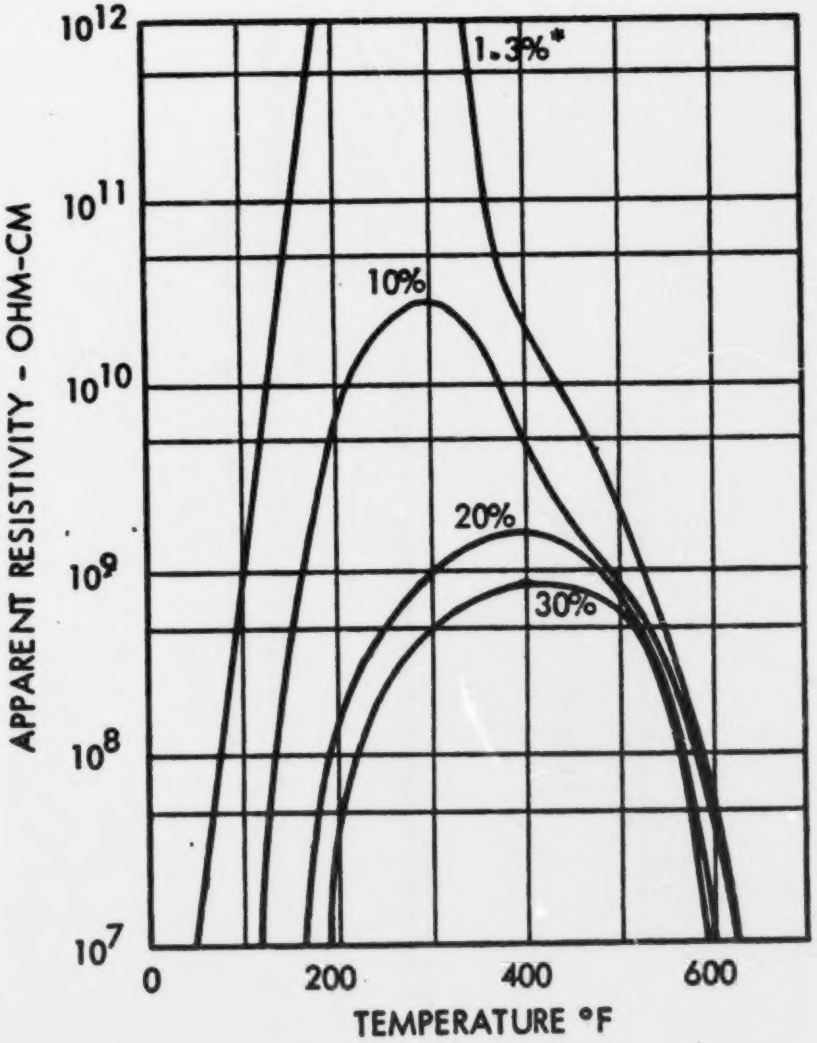
* Figure shows percent water vapor by volume.

Figure 9-6 - Resistivity of Open Hearth Furnace Fume Under Varying Conditions of Temperature and Moisture in Gas1/



* Figure shows percent water vapor by volume

Figure 9-7 - Apparent Resistivity of Fume from Open-Hearth Furnace1/



* Figure shows percent water vapor by volume

Figure 9-8 - Apparent Resistivity of Fume from Open Hearth Furnace1/

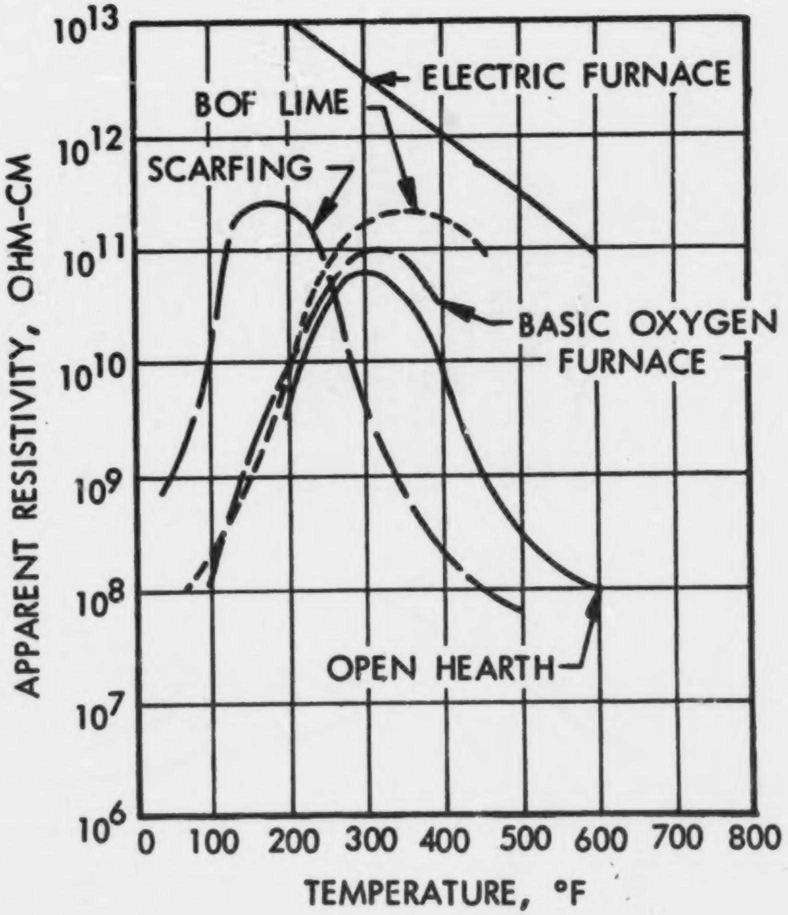
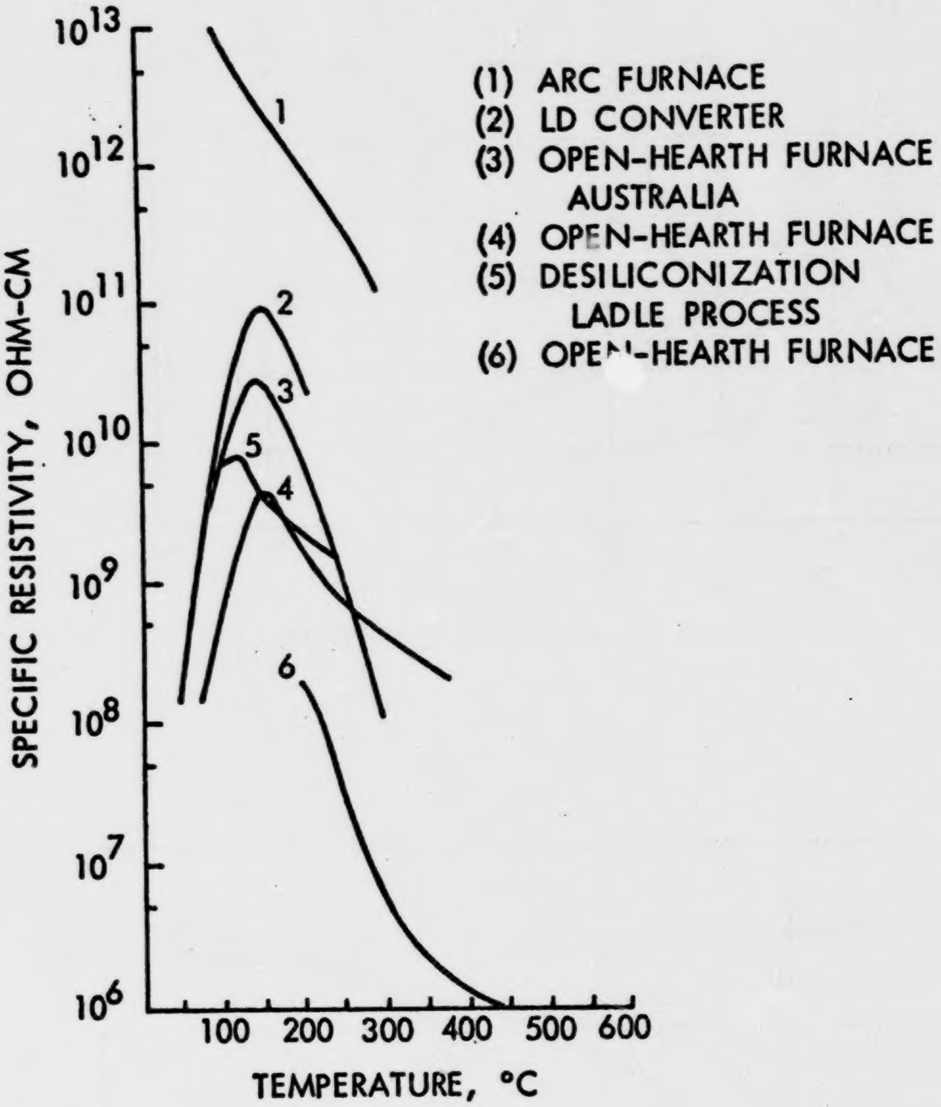


Figure 9-9 - Apparent Resistivities of Metallurgical Dusts1/



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* Figure shows percent water vapor by volume.

Figure 9-10 - Electrical Resistivity of Red Oxide Fume From Various Oxygen-Blown Steelmaking Processes 1/

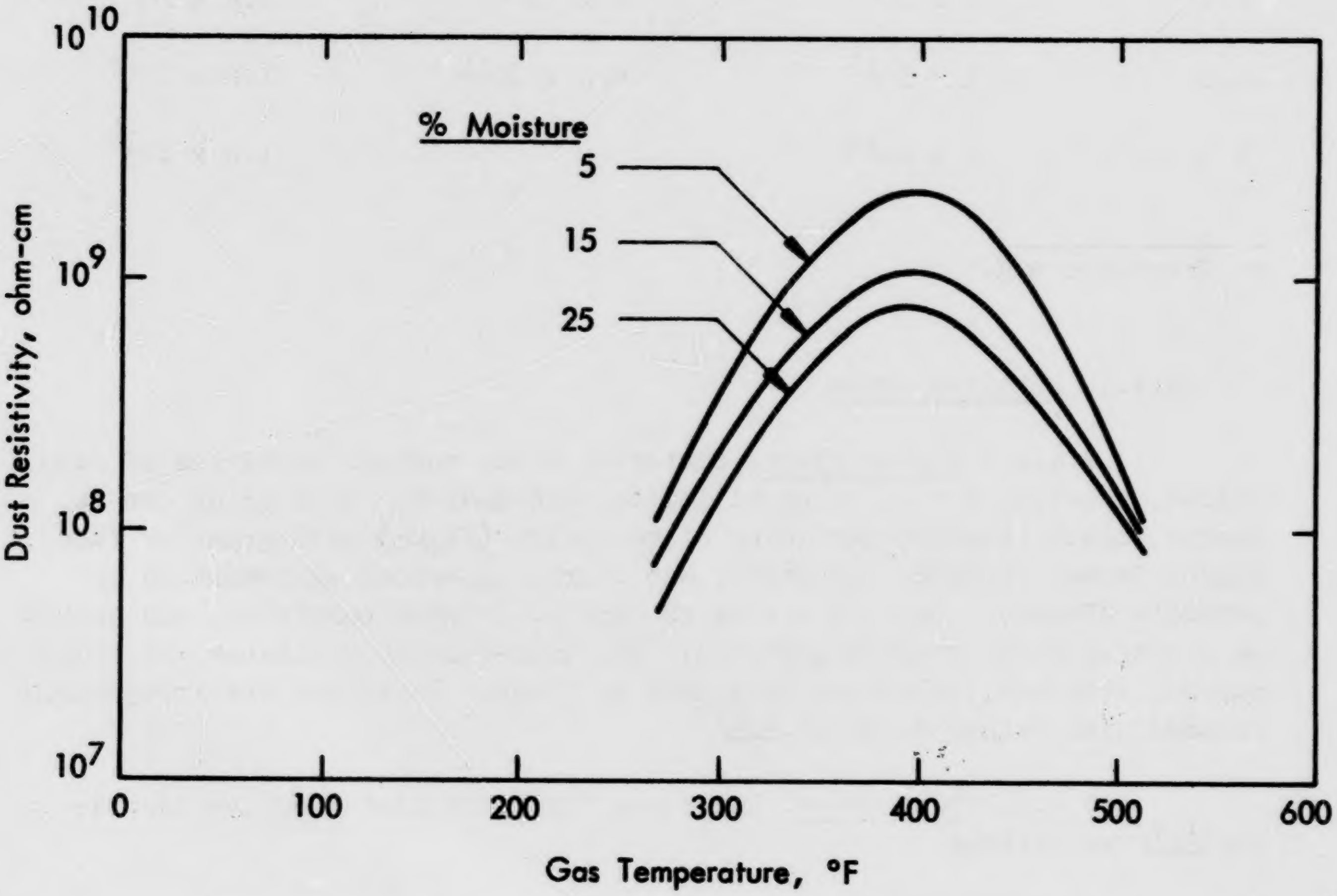

Figure 9-11 - Resistivity vs. Gas Temperature for BOF Furnace Dust[36]
(Laboratory Measurements)

TABLE 9-4

IRON SINTER DUST RESISTIVITY*
(ohm-cm)

%H_2O	150°F	200°F	250°F
1.4	2×10^{10}	3×10^{10}	1.6×10^{12}
3.0	1×10^{11}	6.5×10^{11}	1.6×10^{12}
9.0	9×10^{10}		1.6×10^{12}

---

* Discharge end.

9.4.1 Particle Shape

9.4.1.1 Sinter Plant: Sinter dust may contain particles of iron oxides, calcite, iron-calcium silicates, and quartz. Iron oxide can be opaque, black, rounded particles of magnetite (Fe_3O_4) with granular faces, and/or dense, rounded, elongated, and nearly spherical agglomerates of hematite (Fe_2O_3). Calcite occurs as smooth, rounded particles, and quartz as a transparent, rounded particle. The iron-calcium silicates are transparent, vitreous, colorless to yellow to green. Particles are irregularly rounded with smooth surfaces.1,6/

9.4.1.2 Coke Ovens: Emissions from coke plants can be identified1,7/ as follows:

9.4.1.2.1 Coal dust: Bituminous, or soft coal, is translucent in thin areas: it is reddish-brown by transmitted light, and brownish-black with dull to moderately high reflectivity in reflected light. The surfaces are slightly rough with occasional indications of the original fibrous structure. These irregular chips have sharp edges, and in places show conchoidal surface fractures.6/

9.4.1.2.2 Coke balls: Oval in shape with an unusual network-like internal structure. It has been suggested that coke balls are produced during the thermal-drying stages of coal processing. Similar conditions occur during charging or by-product coke ovens, where some coal fines are carried through the hot zone and out adjacent, open charging holes.7/

9.4.1.2.3 Char: Partially devolatilized coal particles exhibit optical properties between those of coal and coke. The partial devolatilization of coal particles suggests that they have not been subjected to temperatures high enough or for periods long enough to complete the coking process.[7]

9.4.1.2.4 Pyrolytic carbon: A tarry residue comes from the volatile organic portion of coal. Two forms of pyrolytic carbon have been identified. The first is an aggregate of minute oval grains; each grain is relatively uniform in size, extremely smooth in appearance, and exhibits extreme anisotropy in polarized light. The second normally occurs as a crenulated band of varying width and length, is smooth in appearance, and is strongly anisotropic in polarized light. The size of these materials is extremely variable.[7]

9.4.1.2.5 By-product coke: The optical characteristics of particles of by-product coke are controlled by the rank (reflectance) of the coal which is carbonized. Because coals of different rank are usually blended to make an optimum mix, particles of coke produced from these mixes have complex and highly variable optical properties. Particulates of coke made from high-volatile and medium-volatile coals may be granular in appearance, have thick coke walls, and have few internal pores. Particulates from coke made with low-volatile coals have distinctive ribbon-like textures, thin coke walls, and comparatively large internal pores.[7]

9.4.1.3 Blast Furnace: Particulate emissions generated in the making of iron in the blast furnace and in its immediate auxiliaries have the following characteristics:[1]

9.4.1.3.1 Iron-ore dust: Particles are rounded to elongated in shape and can be as small as 2 μ. Larger particles are opaque and red-orange in top light. Individual small grains are transparent and blood-red.[6]

9.4.1.3.2 Coke dust: Particles are opaque, irregularly shaped, quite porous and rough with some straight, sharp edges. They are gray-black in reflected light.[6]

9.4.1.3.3 Limestone dust: Calcite. It is colorless, with light-transmitting characteristics varying from transparent to translucent. Particles generally occur as rhombohedra because of their perfect rhombohedral cleavage. Fragments may also occur as prisms.[6]

9.4.1.3.4 Flue dust: Blast furnace flue dust typically contains 15% metallic iron, 40% red iron oxide, 40% magnetic iron oxide, and 5% limestone,[6] but many variations exist:

a. Iron--fragments are opaque, black, and sharp, magnetic with finely granular surfaces.[6]

b. Red iron oxide--particles are transparent, rounded grains, usually less than 2 μ in maximum dimension.[6]

c. Magnetic iron oxide--particles are opaque, black, rough fragments, partially or completely covered with red iron oxide.[6]

d. Limestone dust--particles are transparent, colorless rhombohedra, and rounded; many may also be covered with red iron oxide.[6]

9.4.1.3.5 Kish: Carbon in the form of flaky graphite that is rejected by the molten iron as it cools during flow from the blast furnace to ladles. Other types of particles may be entrained with this kish. The graphite particles are opaque, black, sharply angular flakes with smooth surfaces. Some are in layered agglomerates, occasionally showing rounded 120-degree angles, and even forming rounded hexagonal tablets. Other particles accompanying the kish may consist of opaque, black, rather coarse fragments of magnetic iron oxide, and transparent, deep-red, rounded particles of hematite. Traces of quartz and calcite may also be found with the kish.[6] Graphite typically makes up about 90% of the emission, with the magnetic oxide at 5% and hematite at 5%.

9.4.1.4 Open-hearth Furnace: Open-hearth furnaces generate four major types of particulate emissions.[1]

9.4.1.4.1 Open-hearth dust: Charging period. Two components appear in the dust generated during charging of the furnace. One is a magnetic iron oxide of black, opaque spheres, and elongated, rough particles with sharp jagged edges, all generally coated with red iron oxide. The second component comprises transparent, rounded particles of red iron oxide, usually less than 2 μ in dimension. They occur free or in simple agglomerates.[6]

9.4.1.4.2 Open-hearth dust: Hot metal to lime-up. Three components make up the dust from this period of open-hearth operation. (a) Loose agglomerates of tiny transparent grains are usually less than 1 μ in dimension. It is a hydrated iron oxide such as $HFeO_2$. Individual grains and agglomerates are yellow under top light. (b) Tiny, rounded, transparent, red grains of iron oxide are usually less than 1 μ in dimension. (c) Opaque, black spheres and rounded particles of magnetic iron oxide. Some particles are covered with hydrated iron oxide and/or the red iron oxide.[6]

9.4.1.4.3 Open-hearth dust: Tap to charge. This is the same as Item 1 with the addition of black, opaque, frothy, rounded particles of coke.[6]

9.4.1.4.4 Particulates in combustion product: About 85% of the material is transparent, deep red, rounded grains of iron oxide, usually less than 1 μ in dimension. The remaining 15% is black, opaque spheres 3 to 5 μ in dimension, of magnetic iron oxide. The smaller grains are orange in top light and tend to form simple agglomerates or loose lumps.

All lime dust does not occur as a visually apparent particulate; it is present in open-hearth dust in very small quantities as shown by chemical analysis. Sulfur in the form of sulphates also occurs in open-hearth dust, but information in visual characteristics is not available in the published literature.

9.4.1.5 Basic Oxygen Furnace: The major particulate emissions from basic oxygen furnaces are:

9.4.1.5.1 Kish: Carbon in the form of graphite is rejected by the molten iron as it cools during charging into a BOF steel-making vessel. The graphite particles are opaque, black, sharply angular flakes with smooth surfaces. Some are in layered agglomerates, occasionally showing rounded 120-degree angles, and even forming rounded hexagonal tablets. Other particles may consist of opaque, black, rather coarse fragments of magnetic iron oxide and transparent, deep red, rounded particles of hematite. Traces of quartz and calcite may also be found with kish.[6]

9.4.1.5.2 Silica fume: Approximately 50 to almost 100% silica material often contains small quantities of iron, manganese, magnesium and carbon. Color of the collected material is grey to off-white.

9.4.1.5.3 Basic oxygen process dust: Tiny (1 μ in dimension), rounded, transparent particles of red iron oxide tend to agglomerate. Shiny black spheres of magnetite are covered with red iron oxide.

9.4.1.6 Electric-Arc Furnace: Emissions from electric-arc furnaces include:

9.4.1.6.1 Electric-furnace dust: Opaque, rounded grains are peach to reddish in color in top light. Small agglomerates are present, but are not common.[6]

The chemical composition of electric-furnace dusts will be influenced by the composition of the steel being melted. Because of this, optical characteristics of the dust may also vary because of the different alloying-element oxides that may be present. Because electric furnaces are used for melting a wide range of alloy and stainless steels, the chemical composition of any particulate dust will reflect the composition of the alloy melted.1/

9.4.1.6.2 Dust from scrap preheaters: Information on the physical and optical characteristics of dust generated during the preheating of scrap is not available. However, it can be assumed that the composition of the dust will be influenced mostly by the cleanliness of the scrap, its content of volatile matter, and presence of surface coatings on some of the steel.1/

9.5 CONTROL TECHNIQUES FOR THE IRON AND STEEL INDUSTRY

9.5.1 Control Practices - General

The operation and types of furnaces associated with the iron and steel industry vary widely. Therefore, the criteria for the type of control equipment are determined by the specific operation. A tabulation of the types of equipment used in the various processes is given in Table 9-5.1/ The installation of fume control systems in the iron and steel-making processes requires considerable instrumentation. This required control instrumentation is discussed and graphically depicted in Reference 9.

The cost of the different types of control equipment for these applications has been reported in a NAPCA document "A Cost Analysis of Air Pollution Controls in Integrated Iron and Steel Industry." Section V of that report presents the cost/effectiveness investigation and the cost models which were developed.8/

The applied control systems are more thoroughly discussed in a companion document, "A Systems Analysis Study of the Integrated Iron and Steel Industry."1/ Excerpts of Section VI of that report are included herein, and the estimated capital and operating costs are summarized in Figures 9-12 - 9-20.

9.5.2 Control Practices - Specific

9.5.2.1 Sinter Plants: Major sources of dust in sintering plants are the combustion gases drawn through the bed, discharge end gas, and the exhaust gases from sinter grinding, screening and cooling operations.10/ Because dust generated in the sintering operation can be returned to the process, most plants are at least equipped with cyclones.

TABLE 9-5

REPRESENTATIVE EMISSION-CONTROL APPLICATIONS IN THE INTEGRATED IRON AND STEEL INDUSTRY[1]

Iron- or Steel-Making Segment	Type of Emission-Control Equipment			
	Mechanical	Scrubbers	Precipitators	Fabrics
Sinter plant	17	2	9	3
Blast furnace[a]	13[b]	51	108	0
Open-hearth furnace	0	6	93	0
Basic oxygen furnace	0	15	23	0
Electric furnace	0	5	1	29
Scarfing	4	4	3	2

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a/ Final control equipment.
b/ Dust collectors followed by other equipment are not considered.

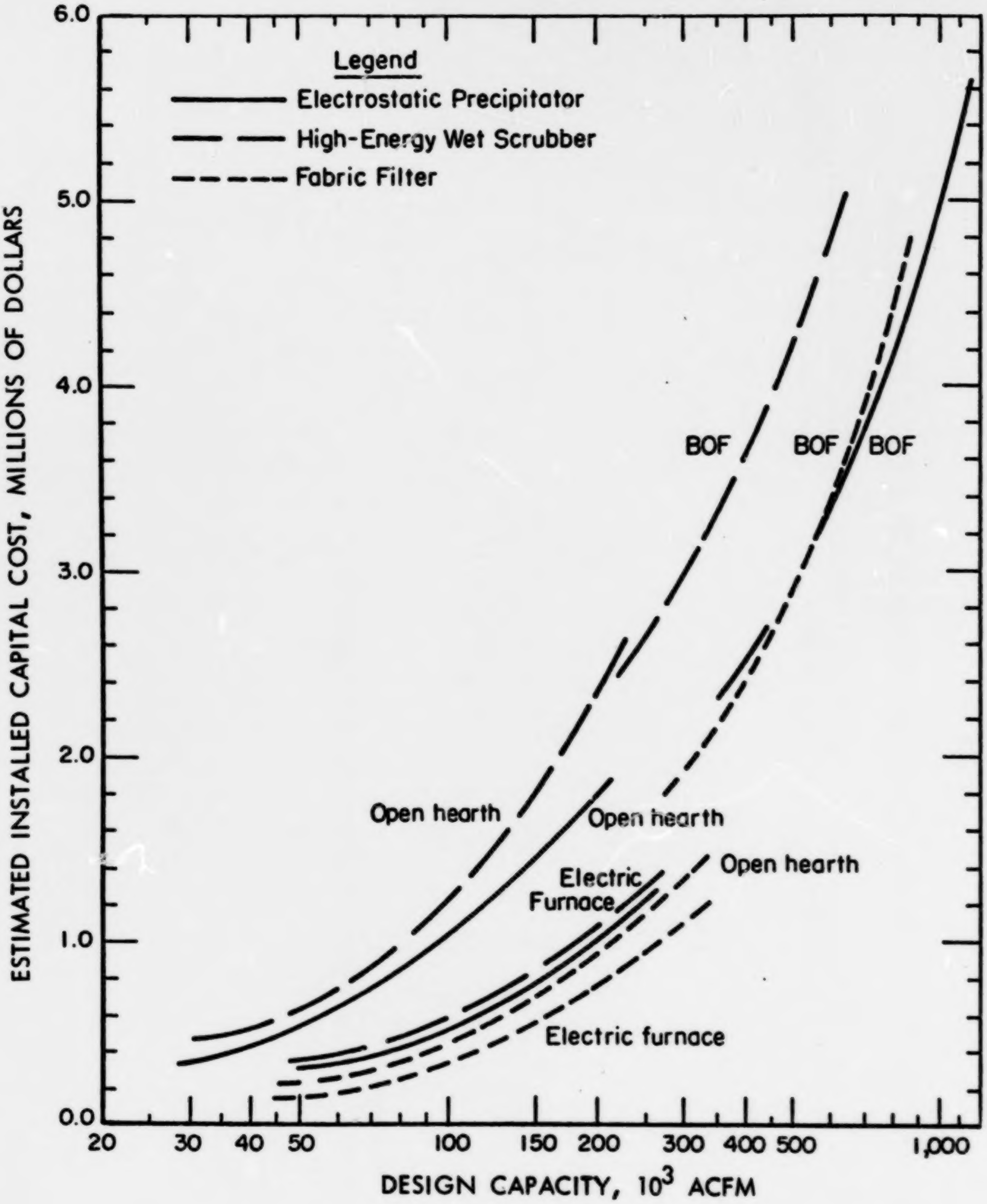

Figure 9-12 - Estimated Installed Cost (1968) of Air-Pollution-Control Equipment as Related to Different Steel-Making Processes[1]

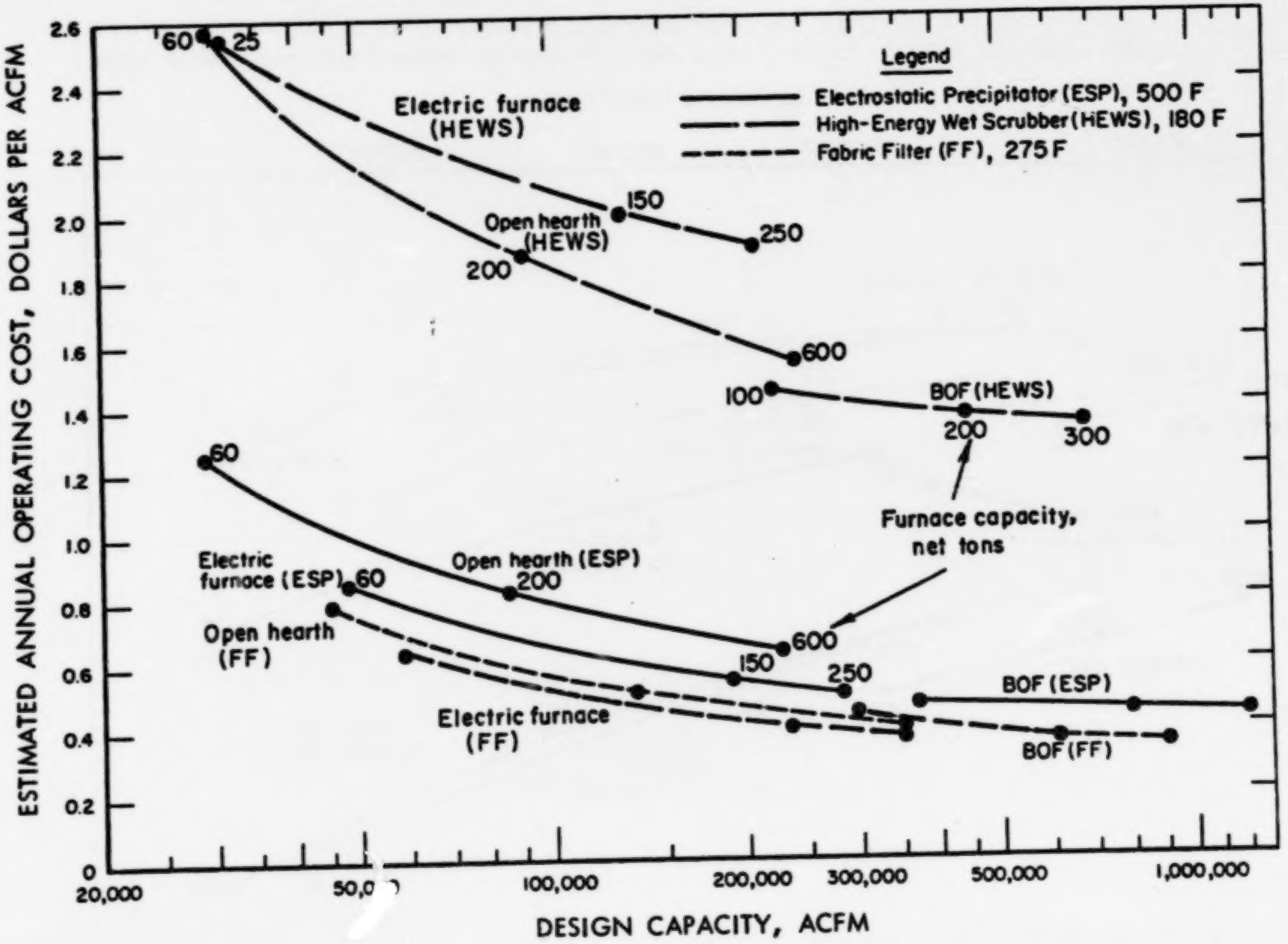

Figure 9-13 - Estimated Annual Operating Costs for Air-Pollution-Control Equipment for Steel-Making Process[1] (Depreciation and Capital Charges are not Included)

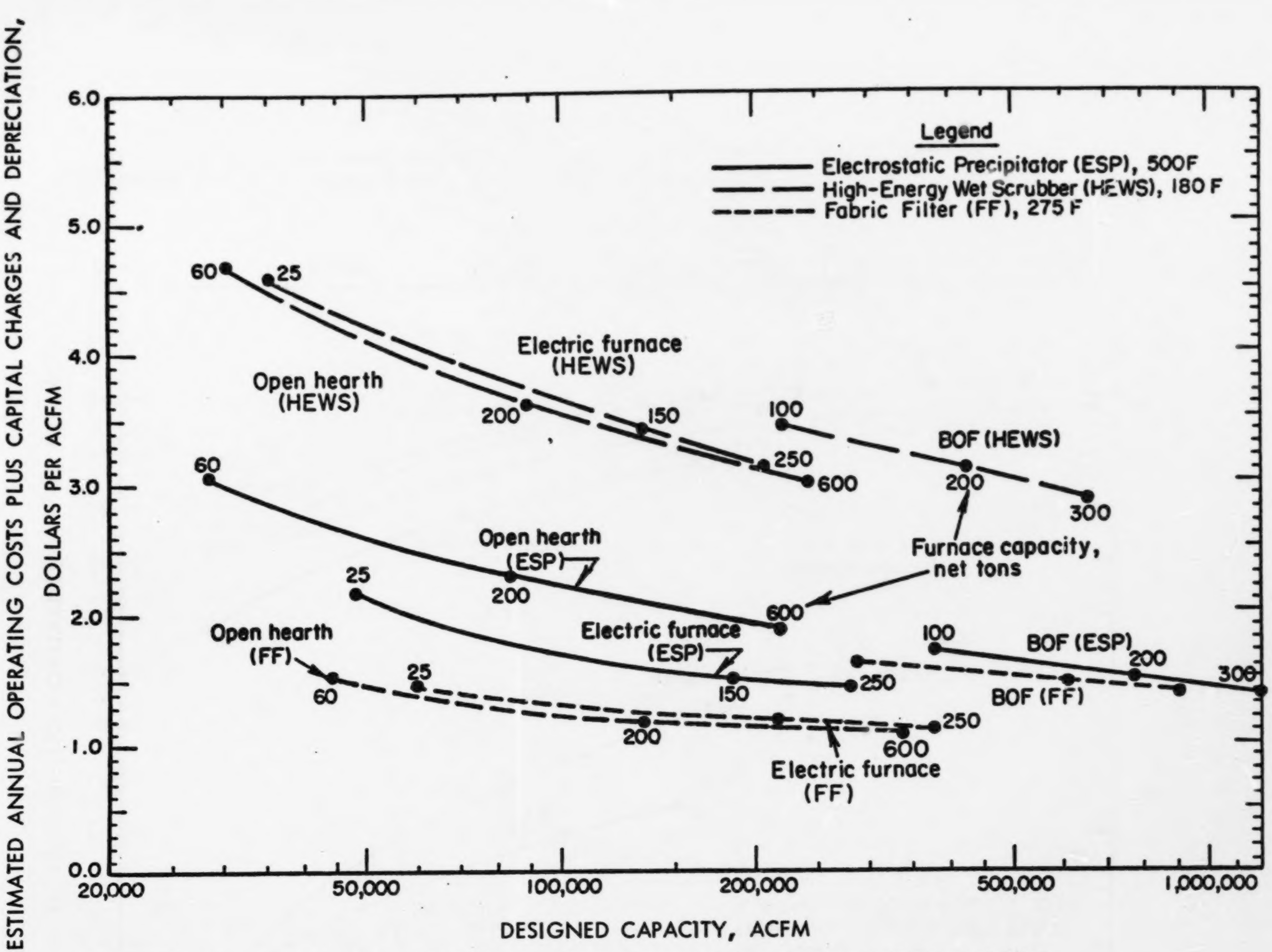

Figure 9-14 - Estimated Annual Operating Costs Plus Capital Charges and Depreciation for Air-Pollution-Control Equipment for Steel-Making Processes[1]

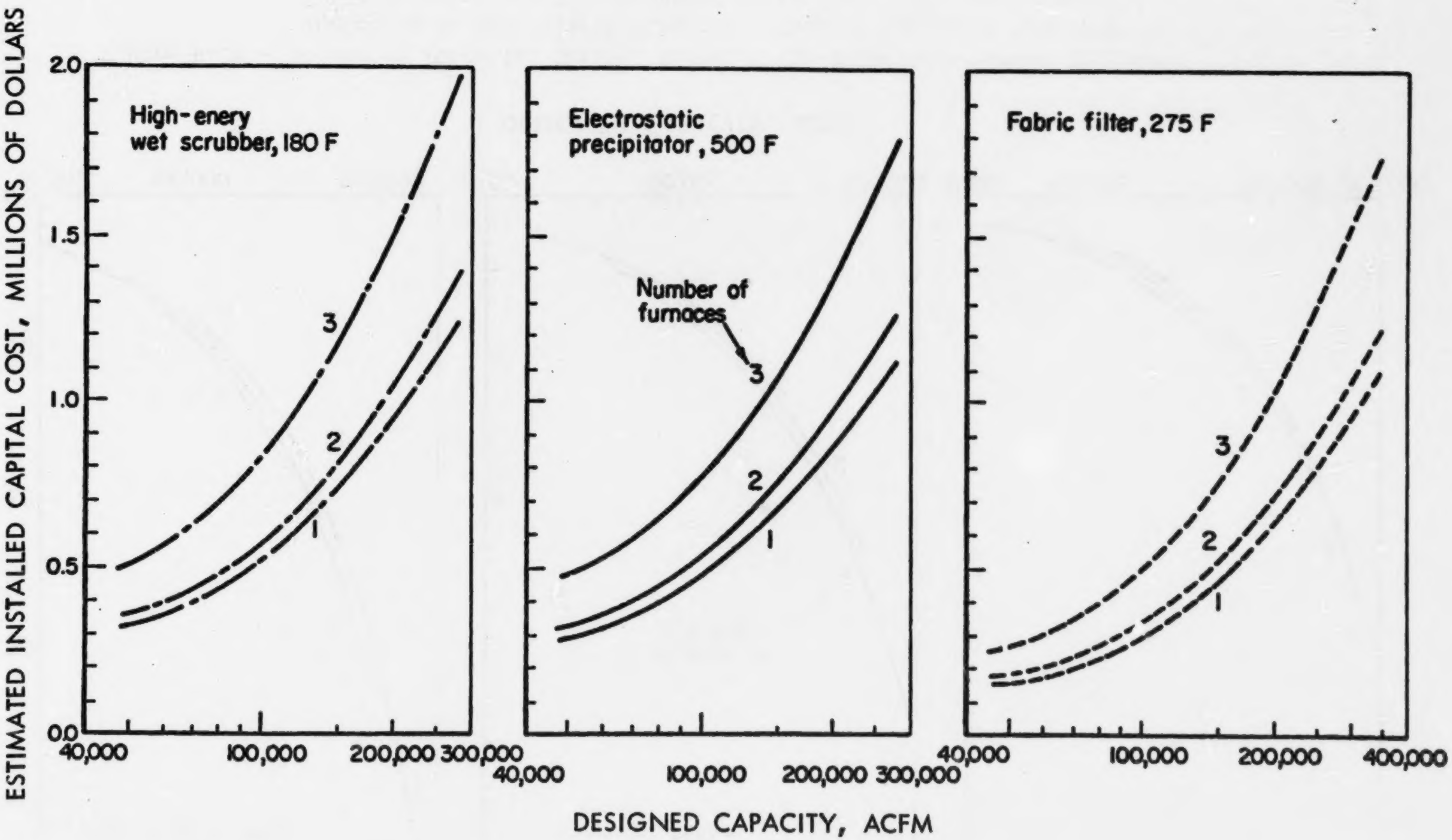

Figure 9-15 - Estimated Installed Capital Costs of Air-Pollution-Control Equipment Installed on Electric-Arc Steel-Making Furnaces. Control equipment designed to handle emissions from any one furnace at one time.[1]

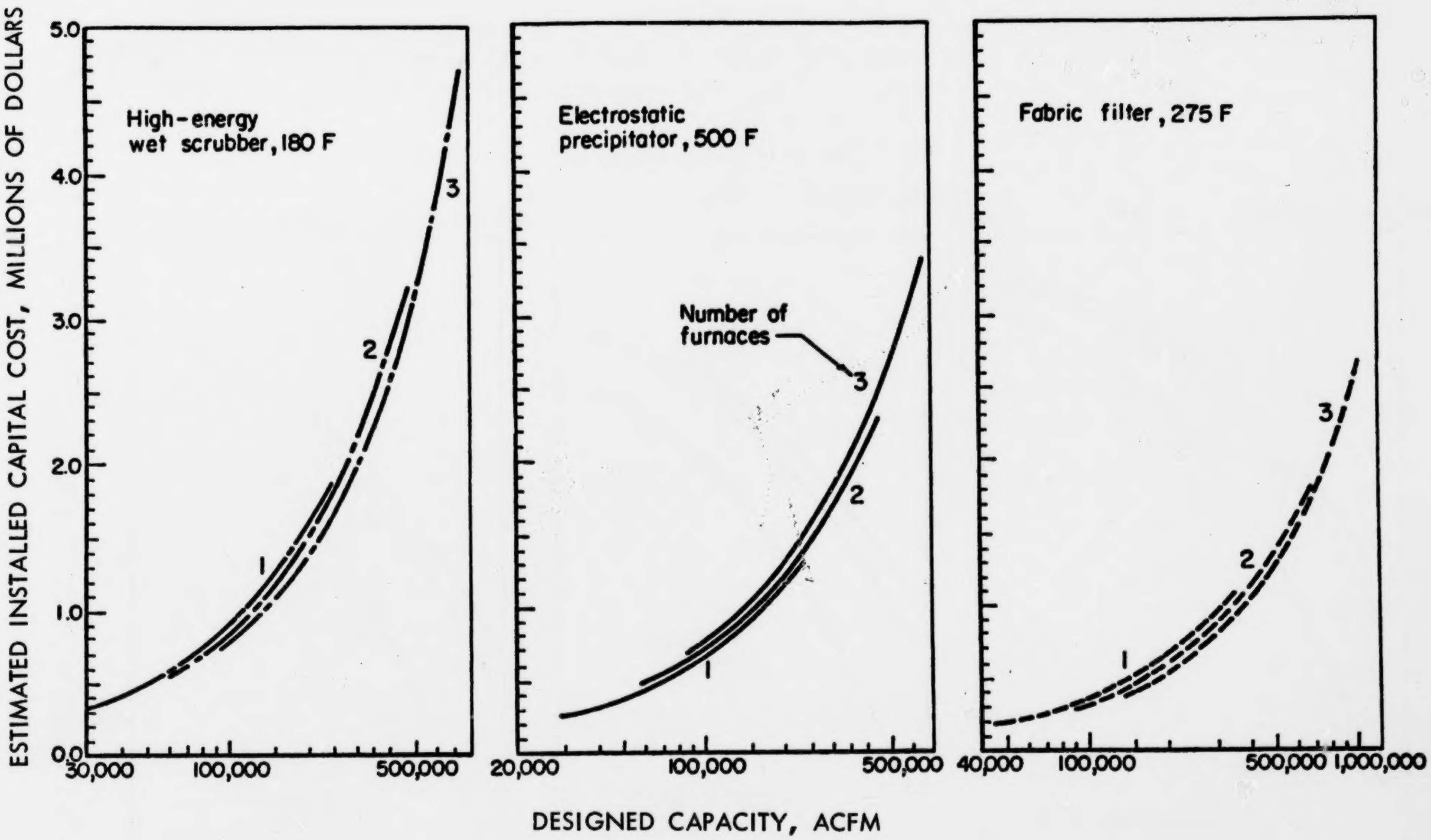

Figure 9-16 - Estimated Installed Capital Costs of Air-Pollution-Control Equipment Installed on Open-Hearth Furnaces. Control equipment designed to handle emissions from furnaces operating at the same time.[1]

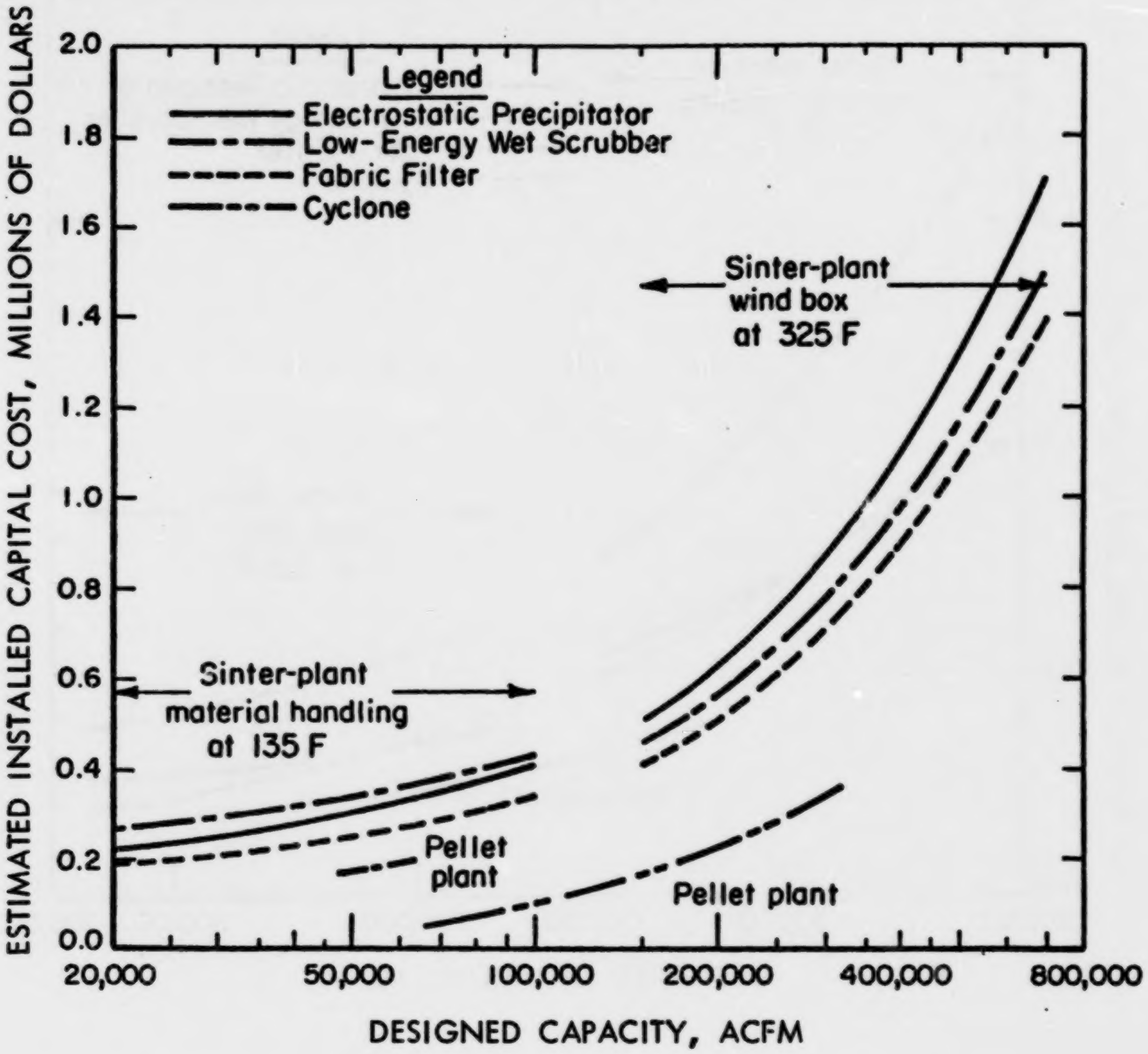

Figure 9-17 - Estimated Installed Capital Costs of Air-Pollution-Control Equipment Used in Sinter and Pellet Plants.[1]

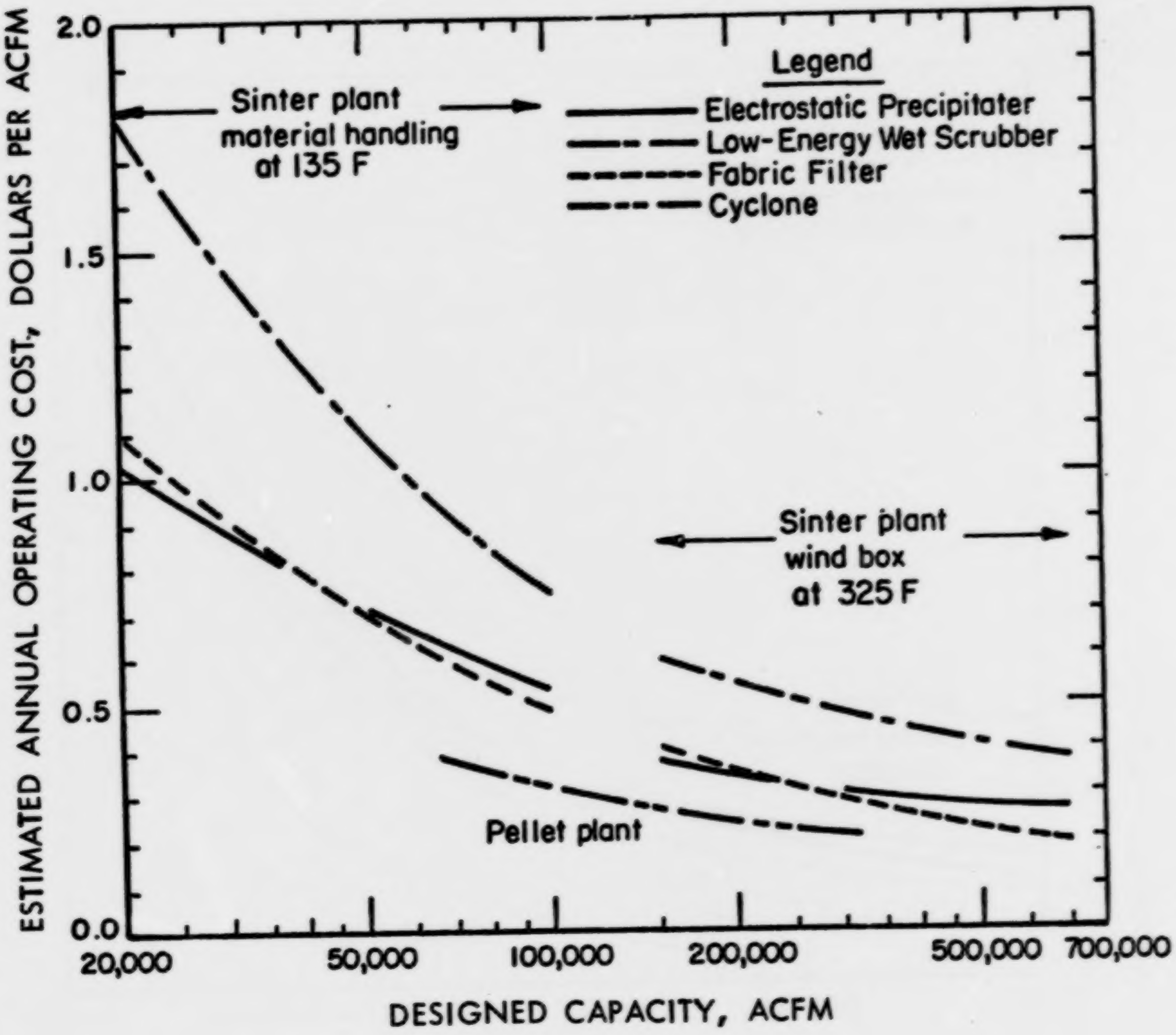

Figure 9-18 - Estimated Annual Operating Costs for Air-Pollution-Control Equipment Used in Sinter and Pellet Plants (Depreciation and Capital Charges are Not Included)[1]

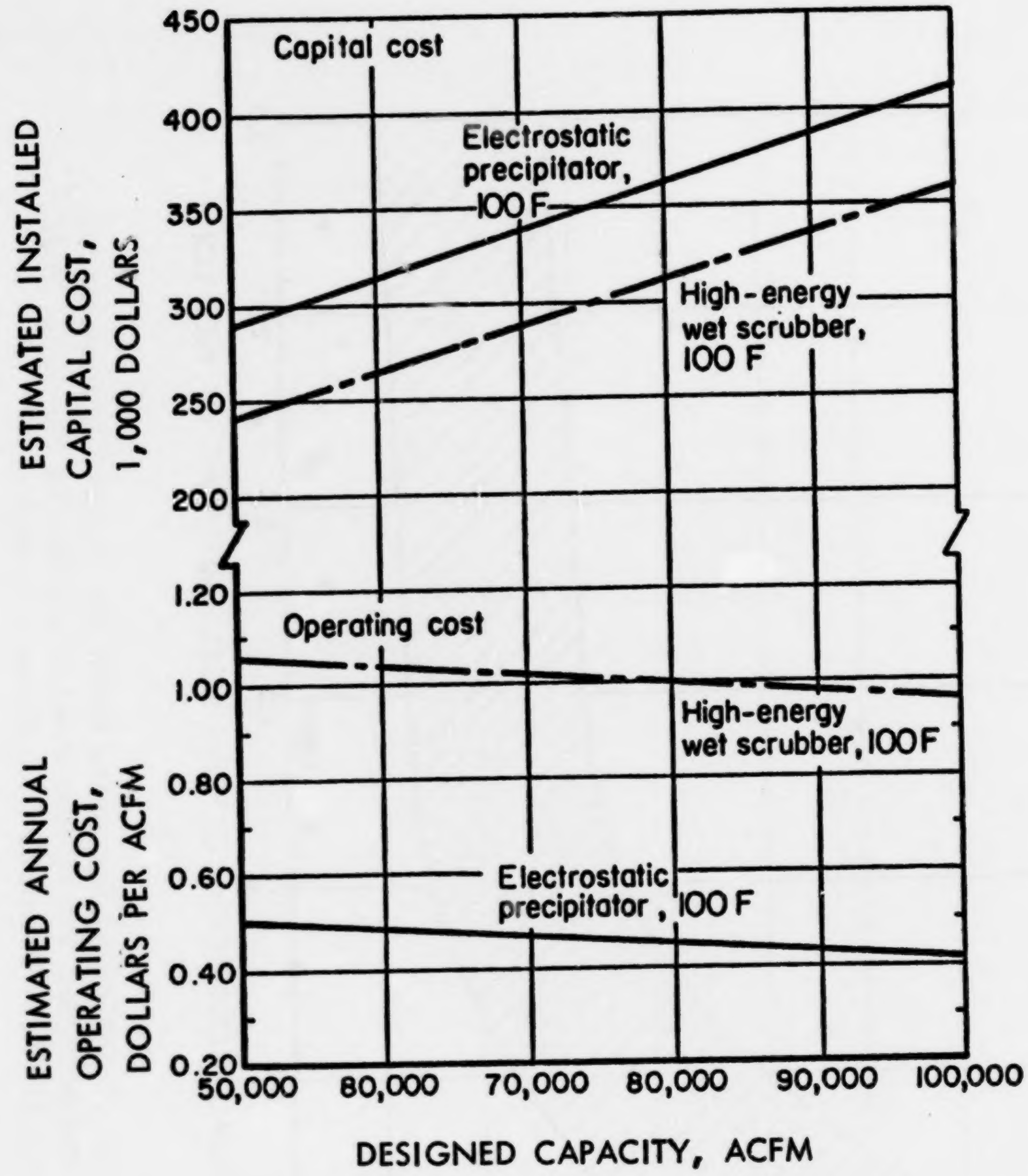

Figure 9-19 - Estimated Capital and Annual Operating Costs for Air-Pollution-Control Equipment Used on Scarfing Machines (Depreciation and Capital Charges are Not Included in the Operating Costs)1/

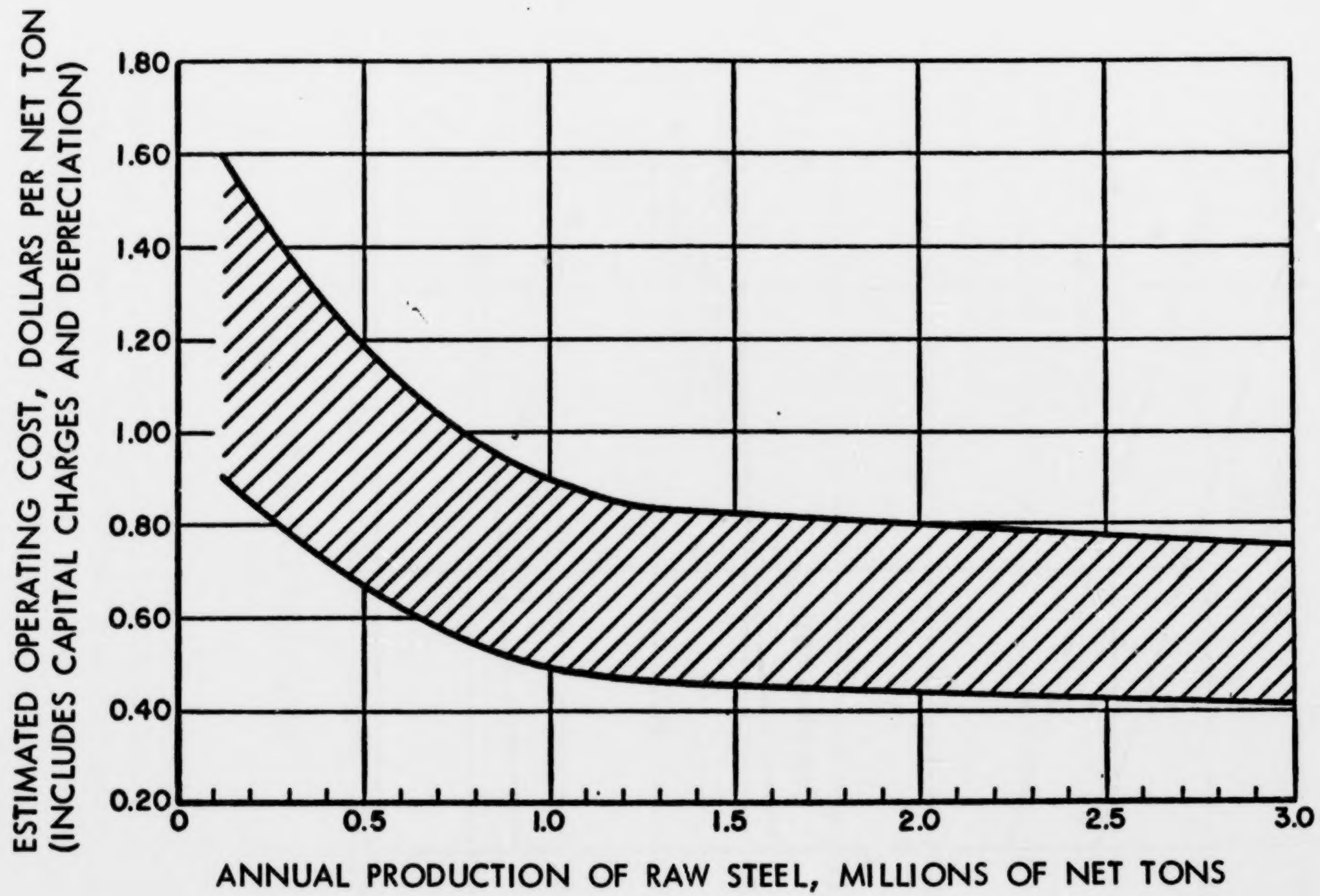

Figure 9-20 - Range of Estimated Operating Costs for Air-Pollution-Control Equipment/Net Ton of Raw Steel--Open-Hearth Furnaces, BOFS, and Electric Furnaces (Two-Furnace Operations)1/

Dry-type cleaners are best suited for this cleaning because the sulfur content of the gas streams can lead to corrosion problems in wet systems. Cyclones, electrostatic precipitators, Venturi scrubbers, and baghouses have been used in various combinations at the various points of emission. However, there are some problems that limit the application of these devices.

Wet scrubbers, which have high maintenance cost because of lime buildup, add to water-treatment problems. Baghouses suffer from the abrasiveness of the dust, as do the fans in the sintering machines. With sinter that contains flux (such as limestone), the efficiency of electrostatic precipitators decreases as basicity of the sinter increases.[1/]

Dust created at the junction points of conveyors has been suppressed by water sprays containing a wetting agent.[11/]

9.5.2.1.1 Cyclones: Because of the large particle size, cyclones applied to sintering plants usually operate at over 90% efficiency by weight. However, cyclone exit loadings range from 0.2 - 0.6 grain/ft^3.[10/]

9.5.2.1.2 Electrostatic precipitators and baghouses: High-efficiency baghouses and electrostatic precipitators offer promise of much better collection than the cyclones normally used. However, few have been applied to sintering machines.[10/]

Electrostatic precipitators have been installed in series with cyclones. One such installation is reported to operate at an efficiency of 95%, and the final discharge contains only 0.05 grain/scf.[2/] Another installation handled 457,000 cfm with an inlet loading of 2.5 grains/scf and yielded an output loading of 0.038 grain/scf, an efficiency of 98.5%. However, the materials charged to the sintering machine have changed from straight ore fines to ore, flue dusts, and lime. The characteristics of the ore used have also changed. These changes in materials have resulted in an increased output loading of 0.25 grain/scf, a decrease in collection efficiency to 90%.[1/] The use of self-fluxing sinter has also impaired the operation of electrostatic precipitators in this service at other plants.

There are only three known applications of baghouses at sinter plants.[1/] Data are given in Table 9-6.[1,12/]

9.5.2.1.3 Wet scrubbers: Only two known sinter plants have wet-scrubber installations. Operating problems occur due to erosion and imbalance of fan blades. Dust carried over to the exhaust fans is moist and has a tendency to accumulate on the blades.

9.5.2.2 Coke Production and Coke Ovens: Gaseous and particulate matter relased in the by-product coking operation, except that which escapes from ovens to the atmosphere, are conveyed in ducts to a coal chemical

TABLE 9-6

DESIGN AND OPERATING DATA FOR SINTER-PLANT[1] FABRIC FILTERS ON SINTER STRAND DISCHARGE

Design or Operating Variable	U. S. Steel Corp., Gary, Indiana	Bethlehem Steel Corp., Bethlehem, Pa.
Volume of Air, cubic feet per minute:	172,000 at 255 F	240,000 at 350 F
Suction, inches of water:	12	n.a.
Pressure Drop Across Bags, inches of water	4	n.a.
Hoppers in Unit, number	10	16
Bags per Hopper, number	88	72
Total Bags, number	880	1,152
Bag Size:		
Diameter, inches	11.5	12
Length, feet	32.2	28
Bag Type	Fiberglass	Fiberglass
Bag Life, months	17	36
Bag Permeability, cfm per ft^2 of cloth	12-20	n.a.
Air-to-Cloth Ratio (Normal), cfm per ft^2 of cloth	2.17	2.29
Air-to-Cloth Ratio (One Compartment Cleaning), cfm per ft^2 of cloth	2.41	2.44
Air Temperature, F	175 to 300	200 to 500
Theoretical Design Efficiency, percent	99+	99+

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n.a. - Not available.

processing plant for recovery of chemicals. The coke-oven gas remaining after these operations has a gross heating value of about 525 Btu/ft^3 and is used as fuel throughout the steel plant.

Emissions occurring from handling operations, primarily charging and pushing, and leakage from oven doors, etc., present dust containment problems that are difficult to control. However, a technique to control emissions during charging is being developed at the Pittsburgh Works of Jones and Laughlin Steel Corporation, under the sponsorship of the National Air Pollution Control Administration and the American Iron and Steel Institute, to eliminate this emission by minimizing the openings through which smoke can escape and, more importantly, by creating a slight vacuum inside the oven during charging so that air flows into the openings instead of smoke coming out. Engineering studies are also under way to develop designs for control of coke-oven emissions during pushing.[30/]

The quenching of hot coke in quench towers produces a rising cloud of steam in the chimney which lifts coke dust into the atmosphere. Most of this dust appears to fall out in the vicinity of the quench tower. Baffles installed in a quench tower can reduce the emission of particulates into the atmosphere by 75% or from 6 lb. down to 1-1/2 lb. of dust per load of coke. This can amount to a capture of 900 lb. of particulates per day from one tower.[1/]

9.5.2.3 Blast Furnace: Under normal conditions the untreated gases from a blast furnace contain from 7 to 30 grains of dust per scf of gas. Most of the particles are larger than 50 μ. Blast-furnace gas-cleaning systems normally reduce particulate loading to less than 0.01 grain/scf to prevent fouling of the stoves in which the gas is burned. These systems are composed of settling chambers, cyclones, low-efficiency wet scrubbers, and high-efficiency wet scrubbers or electrostatic precipitators connected in series.[10/] One of the main reasons for cleaning blast-furnace gas is to render it sufficiently clean for use as fuel. Recovered dust is returned to the iron-making process.

Blast-furnace gas is cleaned in three stages; the first two, at least, are used almost universally throughout the industry. The majority of furnaces have secondary cleaning facilities as well. The three stages and the equipment used in each, along with average outlet dust loading from these stages are:

1. Preliminary Cleaning - settling chamber or dry-type cyclone (3-6 grains/scf)
2. Primary Cleaning - gas washer or wet scrubbers (0.05-0.07 grain/scf)
3. Secondary Cleaning - electrostatic precipitator or high-energy scrubbers (0.004-0.08 grain/scf).

9.5.2.3.1 Electrostatic precipitators: The use of electrostatic precipitators for cleaning blast-furnace gas has come about because of the requirements for cleaner gas for the hot-blast stoves. The operation of these units has been relatively trouble free because the blast furnace is an almost continuous producer of gas and because of a high percentage of the particulate emissions removed by the wet scrubbing systems that have previously been used to clean up the gases. The wet scrubbers also serve to condition the gases, for both temperature and resistivity, prior to their entry into the electrostatic precipitator.

9.5.2.3.2 Wet scrubbers: High performance of a Venturi scrubber can be achieved only if the blast furnace is operating at a high enough top pressure to provide the required pressure drop. Lack of sufficient top pressure has usually required use of an electrostatic precipitator as the final gas-cleaning unit.

The effect of water rate at a constant throat velocity on the outlet dust loading of a Venturi scrubber handling blast-furnace gas is shown in Figure 9-21.[1/] Other operating characteristics are shown in Figures 9-22 and 9-23.[1/]

Great Lakes Steel Corporation (Detroit) has three blast furnaces equipped with high-energy scrubbers. These units have made it possible to clean the gas at a low cost, although there have been troublesome problems in design and operation of equipment. Some of the gas-cleaning results are given in Table 9-7.[13/]

TABLE 9-7

BLAST-FURNACE GAS-CLEANING RESULTS[13/]

	Dust Loading, Grains/Ft^3		
Date	Before Orifice	After Orifice	After Precipitators
March 30, 1966	6.0881	0.0208	0.0010
May 11, 1966	13.9233	0.0600	0.0104
May 19, 1966	13.0181	0.0160	0.0141
May 25, 1966	7.2084	0.0293	0.0017
June 1, 1966	10.1117	0.0219	0.0048
June 8, 1966	11.6293	0.0258	0.0047
June 22, 1966	12.2045	0.0581	0.0040
June 29, 1966	10.5555	0.0299	0.0206
July 7, 1966	9.7877	0.0214	0.0099
July 13, 1966	11.0075	0.0293	0.0140

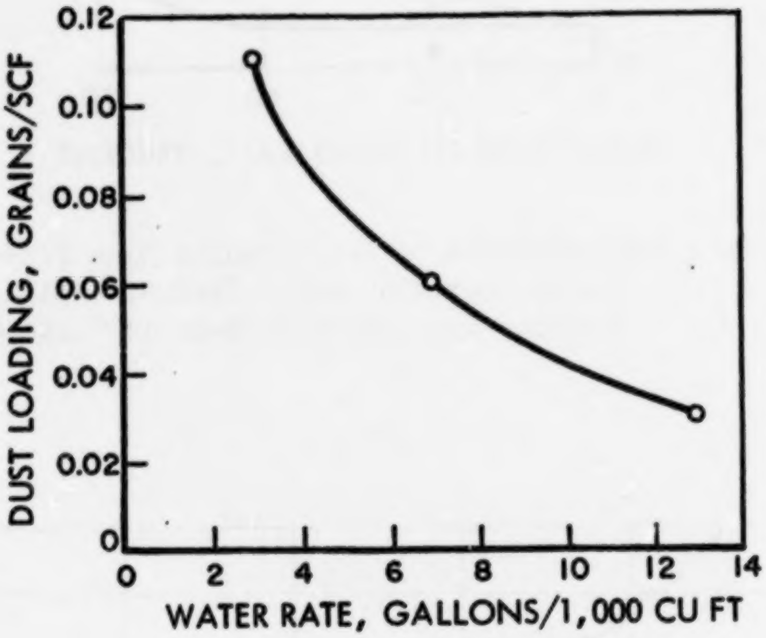


Figure 9-21 - Effect of Water Rate on Output Dust Loading for a Venturi Scrubber Handling Blast-Furnace Gas[1]

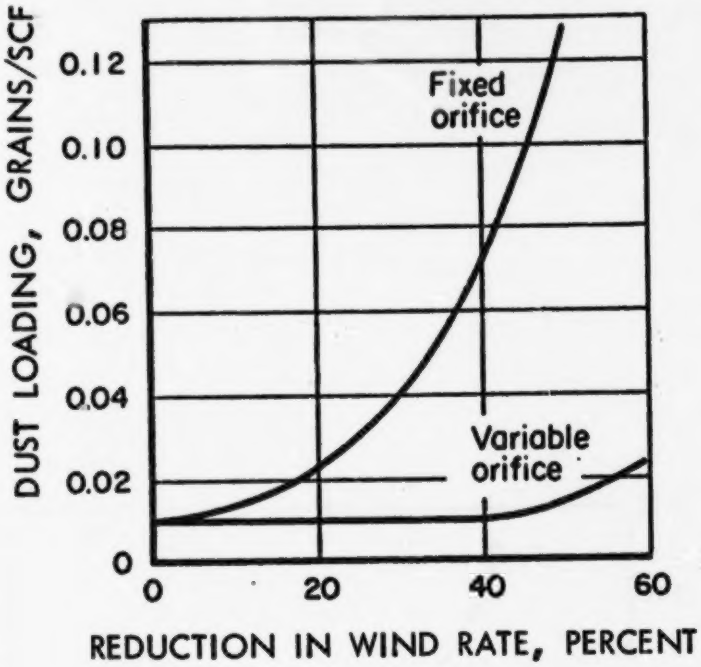


Figure 9-22 - Effectiveness of Gas Cleaning by a Fixed-Orifice Scrubber and a Variable-Orifice Scrubber When Gas-Flow Rate is Varied[1]

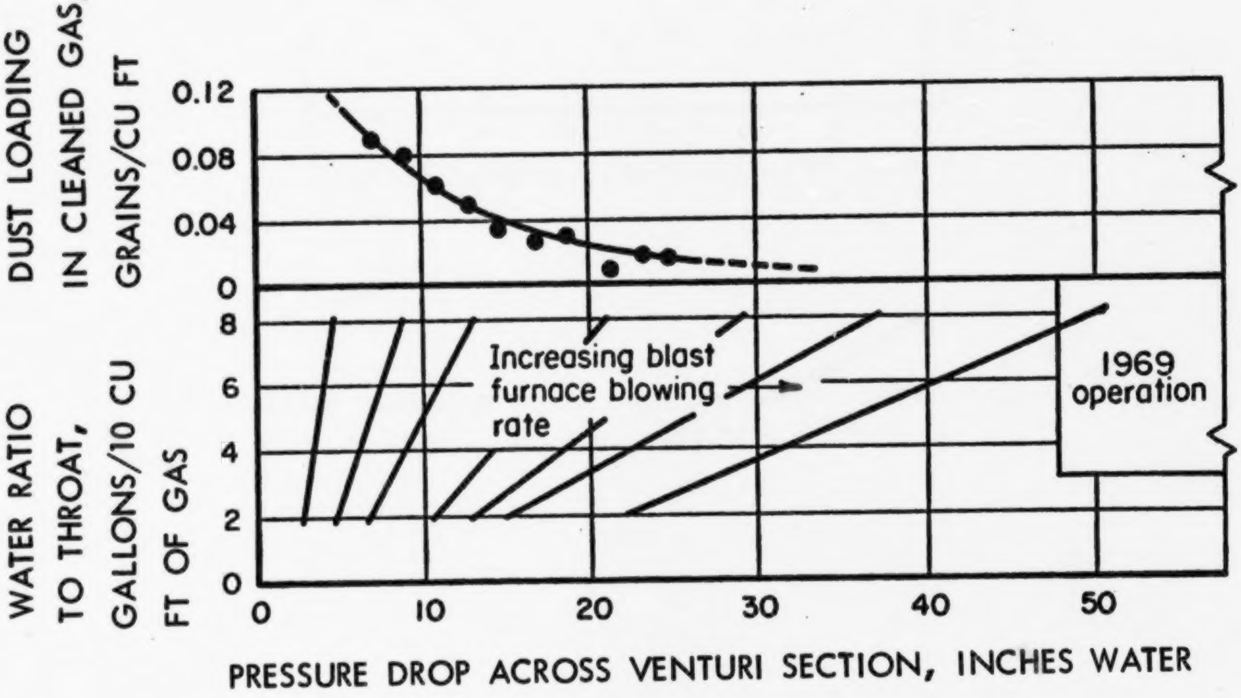


Figure 9-23 - Operating Characteristics of a Blast-Furnace Venturi Scrubber[1]

9.5.2.4 Open-Hearth Furnace: The small size of the particles emitted from open-hearth furnaces requires high-efficiency collection equipment such as Venturi scrubbers and electrostatic precipitators. Because of the cost involved and the growing obsolescence of open-hearth furnaces, industry has been reluctant to invest money in the required control equipment. Often these furnaces have been replaced by controlled basic oxygen furnaces and electric furnaces.

However, electrostatic precipitators, Venturi scrubbers and baghouses are being used on open-hearth systems.8,16/ Exit gas loading would have to be reduced to at least 0.03 grain/scf to be sure of a clear stack.14/

The use of slag wool filters was investigated about 1958 by the Harvard School of Public Health. However, efficiencies were only of the order of 50% and the project was prior to the advent of oxygen lancing.15/

9.5.2.4.1 Electrostatic precipitators: Two major problems that have faced the steel companies and equipment manufacturers in the installation of electrostatic precipitators for open hearths have been (1) design of the ducts used to carry the gases from the open hearths to the precipitators, and (2) the design of the gas distribution systems at the entrance to the precipitators. The use of transparent gas flow-distribution models is considered to be almost a necessity in the practical design of ducting.

The major problem with respect to actual efficiency of electrostatic precipitators on open hearths is the open-hearth process itself. The problem stems from the variation in the properties of emissions from the open-hearth furnace during a heat. During the period of a heat, the moisture content of the gases may drop from a normal value of 18% to 2%, with a resultant increase in resistivity and drop in precipitator efficiency. The situation may be corrected by steam injection.

The relationship between the collection efficiency and size of a precipitator is shown in Figure 9-24. This figure shows that removing the dust from 315,000 cfm of open-hearth waste gas required 58,300 ft^2 of collecting surface for an efficiency of 95%. An increase in the collecting surface area to 96,500 ft^2 resulted in an increase in efficiency to 99.3%.

References 4 and 18 discuss using electrostatic precipitators to collect the fume from open-hearth furnaces. Another electrostatic precipitator system was put in service in 1965 by Weirton Steel Division, National Steel Corporation. This system is used for the control of fumes from 550-ton and 600-ton capacity oxygen-lanced furnaces. A flow-distribution model was used to facilitate designing a high efficiency unit.

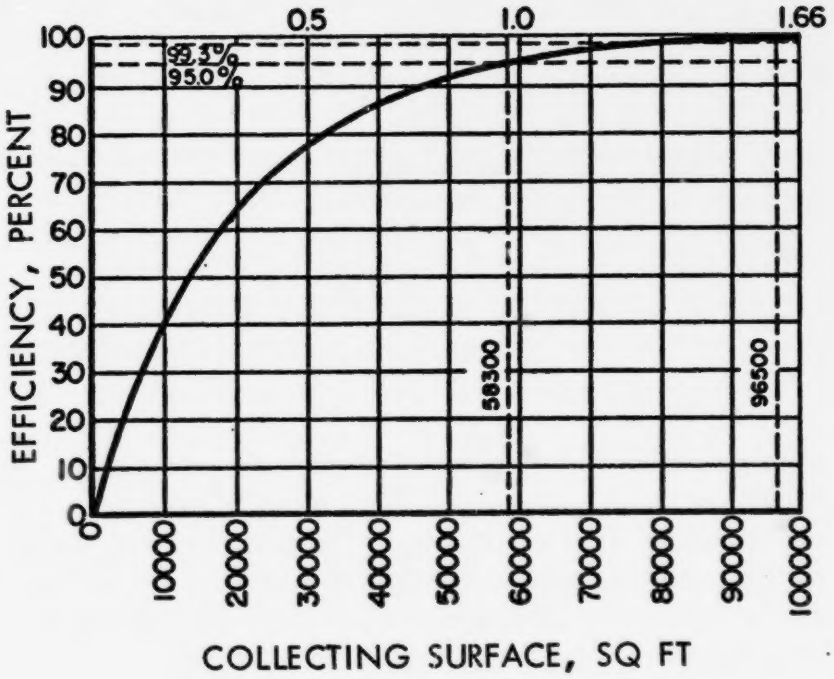


Figure 9-24 - Relationship of Electrostatic Precipitator Collecting Surface to Collection Efficiency for Open-Hearth Emissions (315,000 acfm)1/

Table 9-8 gives the gas flow and dust loadings for different phases of a heat and Table 9-9 shows the results of the performance test conducted during the part of the heat when the dust loadings were at the maximum.[17]

TABLE 9-8

OPEN-HEARTH STACK GAS DATA[17]

	Scrap Charge	Hot Metal	Limeboil	Refine
Dust concentration, grains/scf	0.78	1.9	2.70	0.21
Waste gas flow, scf/min	60,000	64,000	66,000	64,000
Gas temperature, °F	580	600	620	580

TABLE 9-9

PERFORMANCE TESTS OF ELECTROSTATIC PRECIPITATOR ON OPEN-HEARTH GASES[17]

Test No.	Stack Volume Cu. Ft/Min	Temp. (°F)	Sample Volume, scf	Discharge Load, Grains/scf	Estimate Efficiency
1	247,000	500	82	0.007	99.8
2	223,000	460	85	0.019	99.4
3	248,000	440	41	0.010	99.7
4	248,000	440	113	0.016	99.4

9.5.2.4.2 Wet scrubbers: Outlet grain loadings of 0.01 to 0.05 grain/scf have been reported for wet-scrubber installations. The relationship between outlet grain loading and pressure drop is illustrated in Figure 9-25, although it is not necessarily representative of present-day practice using higher oxygen-blowing rates.

A description of the application of Venturi scrubbers to control open-hearth stack emissions is given in Reference 19. Reference 3 describes the application of a Venturi scrubber on a 200-ton open hearth. Tables 9-10 and 9-11[3] give the dust loadings and pressure drops during the oxygen and nonoxygen periods. It is pointed out that the investment and operating costs of a Venturi scrubber system would compete very favorably with those of a precipitator-waste-heat boiler system for cleaning the gas from open-hearth shops that have an anticipated operating life of no more than a few years.

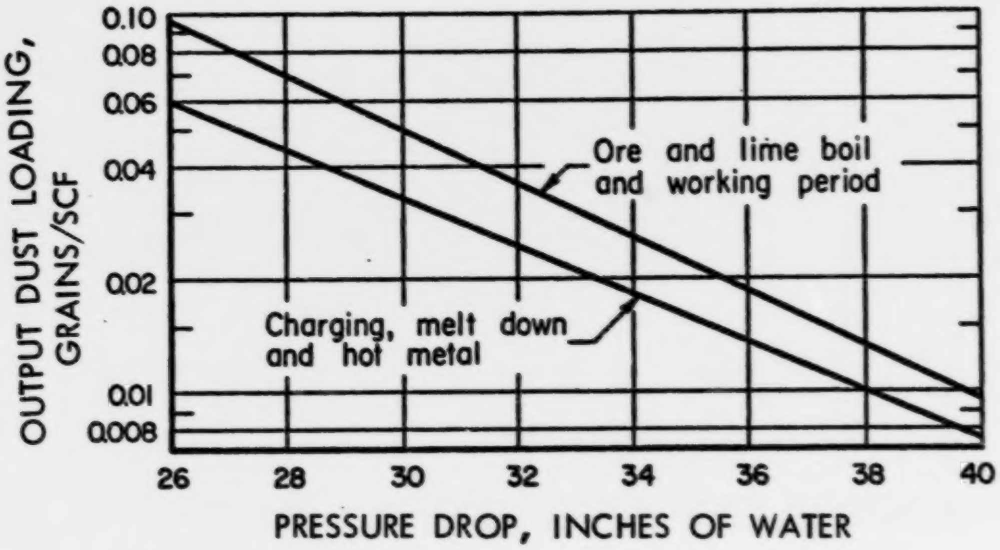


Figure 9-25 - Relationship Between Clean-Gas Dust Loading and Pressure Drop for a Wet Scrubber on an Open-Hearth Furnace (Oxygen Lancing Used During the Refining Period)[1]

TABLE 9-10

SCRUBBER-PRESSURE DROP VS. CLEANING EFFICIENCY AND OUTLET DUST LOADING (NONOXYGEN PERIODS)3/*

Pressure Drop, Inches Of H_2O	Dust Loading, Grains/Scfd		Cleaning Efficiency (%)
	Scrubber Inlet	Scrubber Outlet	
26	0.35	0.06	86
30	to	0.03	92
35		0.01	96
40	0.45	0.008	98

TABLE 9-11

SCRUBBER-PRESSURE DROP VS. CLEANING EFFICIENCY AND OUTLET DUST LOADING (OXYGEN PERIODS)3/*

Pressure Drop, Inches of H_2O	Dust Loading, Grains/Scfd		Cleaning Efficiency (%)
	Scrubber Inlet	Scrubber Outlet	
26	0.82	0.10	89
30	to	0.05	94
35		0.02	97
40	0.87	0.01	99

---

* Gas flow rate was approximately 40,000 scfm.

Republic Steel Corporation of Buffalo, New York, installed a Venturi scrubber handling 60,000 scfm of waste gases from a 300-ton oxygen-lanced open hearth in 1964. This installation is discussed in Reference 20. The system was designed to reduce the dust content to 0.05 grain/scf of dry gas provided that the inlet loading did not exceed 5 grains/scf of dry gas. The waste gases from this open hearth contained sufficient sulfur from the fuels that the scrubbing slurry had a pH of 3 or less, thus requiring that all contacted materials be adequately protected against corrosion. The major problems experienced were buildup on fan blades, fan noise and failure of redwood mist eliminator elements.[20/]

9.5.2.4.3 Baghouses: One glass-fabric baghouse has been applied to the collection of fume from an oxygen-lanced open-hearth furnace by Bethlehem Steel Corporation in Sparrows Point, Maryland. This unit is described in a 1966 article.[21/] The authors state that the capital cost estimates favored the baghouses over an electrostatic precipitator and the subsequent operating experience has shown the maintenance and operating cost to be approximately half that required on an electrostatic precipitator. This baghouse serves a 380-ton/heat furnace having a waste heat boiler and economizer which cool the gas to below 500°F.[21/]

One baghouse installation was made on an open-hearth system after several pilot studies. However, the actual system installed experienced problems of high pressure drop which had not been resolved when this open-hearth shop was shut down.[12/]

9.5.2.5 Basic Oxygen Furnace: The basic oxygen furnace creates more emissions than the open-hearth furnace, and the particles are smaller. All basic oxygen furnaces in the U. S. are equipped with high-efficiency electrostatic precipitators or Venturi scrubbers. Final effluent from these control devices will contain 0.03 to 0.12 grain/scf. Inlet loadings may vary from 2.0 to 5.0 grains/scf. Table 9-12 presents a list of basic oxygen furnaces and their control equipment.

The major operation causing dust and fume generation is oxygen blowing. The volume of waste gases produced is proportional to the blowing rate. Gau arrived at a design volume rating of 25 scfm of waste gases/cfm of oxygen blowing.[22/] It is common practice to operate BOFs in pairs so that one is operating while the other is relined. Therefore, the two furnaces are usually ducted to one control device. The hood over the BOFs gives rise to problems as the substantial variation in temperatures can cause the structure to warp and crack.

The dust problem in BOFs can be minimized if the entire gas and dust-handling process is considered as one system. Specially designed equipment which supplies a controlled amount of excess air to the hood can reduce the size of requisite waste gas-cooling and dust-collecting equipment. The effect of "controlled combustion" is shown in Table 9-13.

TABLE 9-12

BASIC OXYGEN FURNACE INSTALLATIONS AND ASSOCIATED AIR-POLLUTION CONTROL EQUIPMENT[1/]

		Number	Net Tons Per Heat	Annual Capacity, (Net Tons) March 1969	Future	Startup Date	Electrostatic Precipitator	High-Energy Wet
Alan Wood Steel Co.	Conshohocken, Pa.	2	140	1,250,000		1968	X	
Allegheny-Ludlum Steel Corp.	Natrona, Pa.	2	80	500,000		1966		X
Armco Steel Corp.	Ashland, Ky.	2	160	1,400,000		1963	X	
	Middletown, Ohio	2	200		2,000,000	1969		X
Bethlehem Steel Corp.	Bethlehem, Pa.	2	250	2,500,000		1968	X	
	Burns Harbor, Ind.	2	250		1,800,000	1970		X
	Lackawanna, N. Y.	3	290	4,700,000		1964-66		X
	Sparrows Point, Md.	2	200	2,500,000		1966		X
CF & I Steel Corp.	Pueblo, Colo.	2	120	1,100,000		1961	X	
Crucible Steel Corp.	Midland, Pa.	2	90	1,250,000		1968		X
Ford Motor Co.	Dearborn, Mich.	2	250	2,500,000		1964	X	
Granite City Steel Co.	Granite City, Ill.	2	225	2,200,000		1967	X	
Inland Steel Co.	East Chicago, Ind.	2	255	3,000,000		1966		X
		2	210		2,000,000	1973		X
Interlake Steel Corp.	Chicago, Ill.	2	75	730,000		1959	X	
Jones & Laughlin Steel Corp.	Aliquippa, Pa.	2	80	1,000,000		1957	X	
		3	200	3,000,000		1968	X	
	Cleveland, Ohio	2	225	2,250,000		1961	X	
Kaiser Steel Corp.	Fontana, Calif.	3	110	1,440,000		1958	X	
McLouth Steel Corp.	Trenton, Mich.	2	110			1958	X	
		1	110	2,800,000		1960	X	
		2	110			1969	X	
National Steel Corp. Great Lakes Steel Div.	Ecourse, Mich.	2	300	3,500,000		1962	X	
		2	200		2,000,000	1970	X	
Weirton Steel Div.	Weirton, W. Va.	2	325	3,400,000		1967		X
Republic Steel Corp.	Buffalo, N. Y.	2	100		1,000,000	1970	X	
	Cleveland, Ohio	2	240	2,400,000		1966	X	
	Gadsden, Ala.	2	190	1,500,000		1965	X	
	Warren, Ohio	2	180	1,600,000		1965	X	
United States Steel Corp.	Braddock, Pa.	2	220		2,250,000	1972		X
	Duquesne, Pa.	2	215	2,400,000		1963		X
	Gary, Ind.	3	200	3,700,000		1965		X
	Lorain, Ohio	2	220		2,250,000	1970		X
	South Chicago, Ill.	3	150		3,000,000	1969		X
Wheeling-Pittsburgh Steel Corp.	Monessen, Pa.	2	200	1,500,000		1964	X	
	Steubenville, Ohio	2	250	2,000,000		1965		X
Wisconsin Steel Div. International Harvester Co.	South Chicago, Ill.	2	140	1,200,000		1964	X	
Youngstown Sheet & Tube Co.	East Chicago, Ill.	2	265		2,400,000	1969	X	
		TOTAL		57,320,000	18,700,000		23	15

TABLE 9-13

COMPARISON OF EQUIPMENT REQUIREMENTS, ENERGY AND GAS FLOW FOR BOF[23]

System Description	No. 1 100% Excess Air, Injection of Water and Water-Cooled Flue	No. 2 25% Excess Air, Controlled Combustion and Waste-Heat Boiler
Quantity of gas to be cleaned	920,000 actual cfm	176,000 actual cfm
Note	High proportion of leakage air and vapor in the waste gas	Controlled combustion. No vapor in the waste gas, after cooling
Size of filter	8 electric precipitators (1 for spare)	3 electric precipitators (1 for spare)
Energy gain or loss to the system	Approx. 35-kw-hr/ton of steel Loss	Approx. 100-kw-hr/ton of steel Gain
Energy comsumption for the exhaust fans with use of scrubbers (45-in. H_2O pressure drop)	9,500 hp.	1,710 hp.

The gas emanating from the mouth of the furnace is essentially CO and is burned in the hood with induced air. It is desirable to burn all of the CO to CO_2 in the hood; therefore, the hood should be treated as a combustion chamber. A Japanese process has been introduced which does not burn the CO in the mouth of the furnace thereby taking advantage of lower temperature and less volume of gas. The gases are wet-scrubbed and the cleaned gas can be burned at the stack or the CO can be used as fuel. The cost of this system is estimated at $1.0 to $1.5 million for a typical 150-ton BOF.[32]

The factors to be considered in the selection of a wet or dry cleaning system and the problems associated with each system are clearly presented in Reference 24.

Another source of emissions associated with the BOF is kish that is emitted during transfer of hot metal from bottle car to charging ladle. Emissions generated have been reported as 0.16 lb/ton of hot metal with grain loadings of 0.42 grain/scf. A baghouse handling 100,000 acfm has been installed for control of these emissions and is reported to operate at 99.9% efficiency.[33] Experimental studies of fabric filters in this application indicated that air-to-cloth ratio of 4.5 to 1 should not be exceeded. A full canopy hood located just above the ladle, sized for approximately 500 ft/min velocity through all open areas, will usually control the fume.[34]

9.5.2.5.1 Electrostatic precipitators: Problems associated with applications of electrostatic precipitators to basic oxygen furnaces are basically those of variability in gas flow, in the moisture content, and in temperature of the entering gases, as well as maintenance. Also, collection is lower during the initial phase of oxygen lancing before the temperature and water sprays produce a properly conditioned gas stream for efficient collection.

The hoods over the BOF are a necessary part of the collection system, and can result in operating problems. The gap between the BOF and the hood is usually dictated by the anticipated operating conditions and the buildup on the mouth of the furnace ("skull"). Excess buildup can restrict the flow of air required for combustion of the carbon monoxide, with the result that a significant amount of carbon monoxide may reach the electrostatic precipitator with possible disastrous results.

The hot gases leaving the BOF are cooled by heat exchange and water sprays to a preferred temperature of 450° to 500°F. The moisture content of the gas going to the precipitators is quite important; it should be kept between 20% and 30% to insure adequate conductivity of the dust layer.

9.5.2.5.2 Wet scrubbers: Problems associated with the use of wet scrubbers include inadequate water treatment facilities or lack of sufficient water and the abrasive and corrosive nature of the dust-laden water. The dirty water from Venturi scrubbers is cleaned by a combination of liquid cyclones, clarifiers and vacuum filters. The recovered dust may be sintered if the composition is suitable; otherwise it is hauled to storage.

References 25 and 26 discuss the use of wet scrubbers on BOF furnaces. With a wet scrubber system it is not essential to burn all the CO in the hood since a wet system can tolerate a considerable amount of CO without danger of explosion.

9.5.2.5.3 Fabric filters: No installations of fabric filter devices exist in the U. S. However, fabric filters have been applied in Europe. This system uses refractory surfaces in an accumulator to absorb heat from the gases and depends on the cyclic nature of the BOF for its operation. The refractory accumulator absorbs the heat from the gases during the blowing cycle, cooling the gases to approximately 250°F before the baghouse. As soon as the blowing cycle is over, the accumulator is cooled by back-blowing atmospheric air through the accumulator.[27]

9.5.2.6 Electric Furnace: Electric furnaces are becoming more popular for many metal melting operations. Particulate emissions from electric furnaces are difficult to collect because of their small size and because of a strong tendency to adhere to fabric surfaces, a high angle of repose, and high resistivity. Nevertheless, except for difficulties inherent in the charging operation, over 95% effective collection can be achieved with appropriate hooding and high-efficiency collection equipment.[10]

The characteristically small particle size of electric-arc steel furnace fume precludes the use of dry centrifugal collectors, settling chambers, etc. High-efficiency scrubbing systems, electrostatic precipitators and baghouses are used to control fumes from electric-arc steel furnaces.

High-energy scrubbers installed on one oxygen-lanced electric furnace producing a dust concentration of 3.2 to 6.4 grains/scf reduced the dust output to the range of 0.256 to 0.0512 grain/scf. Baghouses reduced it to the range of 0.004 to 0.0064 grain/scf. Electrostatic precipitators, not performing as well, reduced the dust loadings to a range of only 0.256 to 0.512 grain/scf.[1]

The high temperature of the fumes leaving the electric furnace may require the use of tempering air, evaporative coolers or radiation chambers prior to the collection equipment.

Effective dust and fume control during melting and tapping can be achieved. However, a technologically acceptable method has not been found for capturing the heavily polluted air escaping during the charging period. Complete shop evacuation can be used for control of all fumes, but large volumes of air must be handled.

9.5.2.6.1 Electrostatic precipitators: The only known installation of an electrostatic precipitator on an electric furnace plant is at Jones and Laughlin Steel Corporation in Cleveland. The precipitators are considered to be operating satisfactorily. Precipitators installed in 1955 at Bethlehem Steel Corporation in Los Angeles were replaced by baghouses in 1967.

9.5.2.6.2 Wet scrubbers: High-energy scrubbers for electric steel-making furnaces are known to be used in only two plants.

9.5.2.6.3 Baghouses: Fabric filters have been successfully applied to the control of emissions from electric furnaces ranging up to 100 to 150 net-tons capacity, and for multiple-furnace shops as well as one-furnace shops. The application and operating problems for a baghouse installed on a 150-ton electric furnace are discussed in a recent article by W. W. Bintzer and D. R. Kleinton of Lukens Steel Company.[28]

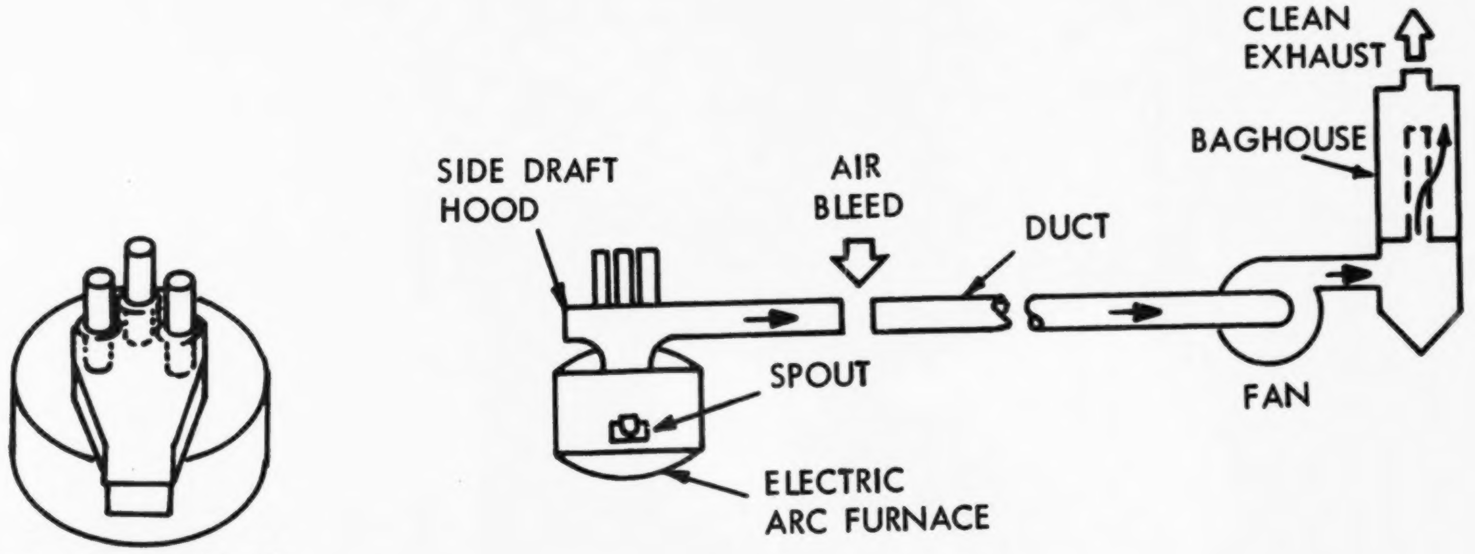
Wherever fluorspar is employed, the fluorides in its off-gas attack glass-filter media. Hence, fiberglass in any form is not recommended on furnaces employing fluorspar as a fluxing agent. However, other synthetic fabrics work well.

The approximate air volumes for various furnace sizes are shown in Table 9-14. Typical side-draft and roof-tap-load systems are illustrated in Figure 9-26.[29]

TABLE 9-14

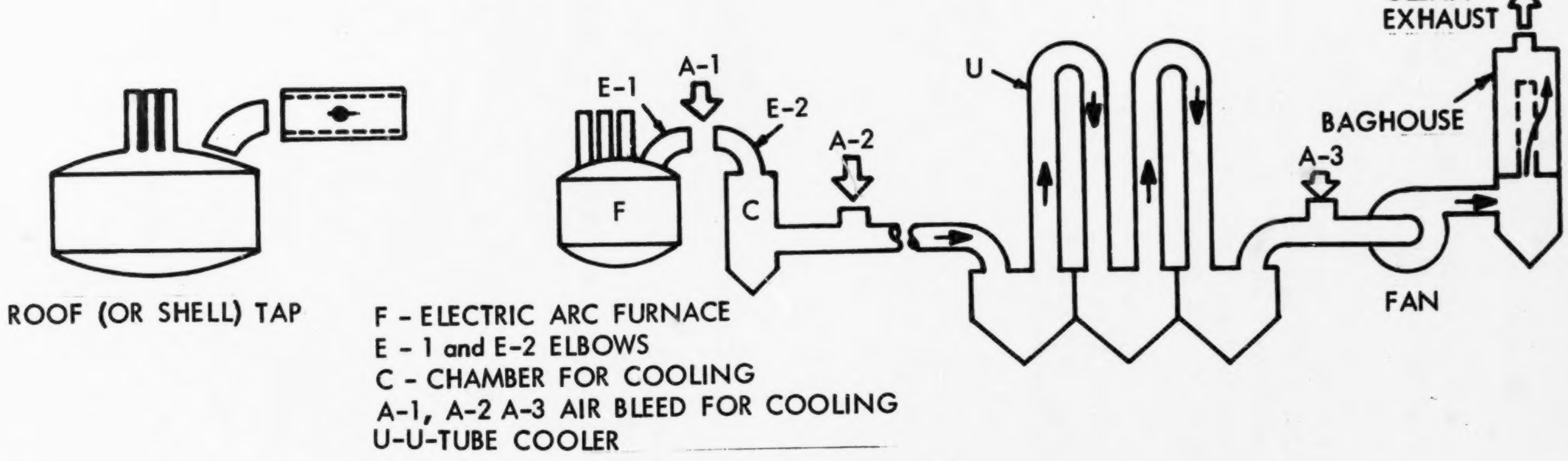
APPROXIMATE BUDGET SIZING CHART[29]
(Air Volume at Standard Conditions (scfm) for Electric-Arc Furnaces)

Roof Ring Diameter (ft.)	KVA	Capacity	Side Draft	Roof Tap
9	4,500	8 tons	18,000	12,000
11	7,000	15 tons	30,000	22,000
13	10,000	25 tons	65,000	50,000
15	18,000	50 tons	80,000	68,000
17	25,000	70 tons	110,000	85,000
19	40,000	100 tons	155,000	115,000
22	60,000	150 tons	190,000	165,000



SIDE DRAFT HOOD

DIAGRAM OF A TYPICAL SIDE DRAFT HOOD SYSTEM



ROOF (OR SHELL) TAP

F - ELECTRIC ARC FURNACE
E - 1 and E-2 ELBOWS
C - CHAMBER FOR COOLING
A-1, A-2 A-3 AIR BLEED FOR COOLING
U-U-TUBE COOLER

DIAGRAM OF A TYPICAL ROOF TAP SYSTEM

Figure 9-26 - Typical Side-Draft and Roof-Tap-Hood Systems for Electric-Arc Furnaces[29]

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CHAPTER 10

CEMENT MANUFACTURE

10.1 INTRODUCTION

Cement, a nonmetallic mineral product, is used as an intermediate product for many materials including concrete, mortar, concrete block and concrete pipe. Raw materials for cement production include lime and silica as the principal constituents, with alumina and ferric oxide as fluxing components. Limestone, cement rock, chalk, marl, shell residues, and blast furnace slag are sources of lime. Five types of cement are produced, the classification determined by limitations on compositions of raw materials and production methods.

Cement is a granular material and dust control is a problem in the industry. Dust emissions result from quarrying and crushing, grinding, kiln, and finish grinding and packaging operations. The manufacturing process, particulate emission sources, emission rates of individual sources, chemical and physical properties of effluents, control practices, and control equipment are discussed in the following sections.

10.2 CEMENT MANUFACTURING PROCESS

Portland cement is made by either the wet or dry process. Figure 10-1 presents a schematic of the two processes. There are four major steps in the production of portland cement: quarrying and crushing, grinding and blending, clinker production, and finish grinding and packaging. Most deposits of cement rock, limestone, clay, and shale are worked in open quarries. The rock is transported from the quarry to crushing plants. The types of primary crushers used depend on the hardness, lamination, and size of rock produced at the quarry, and include gyratory crushers, jaw crushers, roll crushers and heavy hammer mills or impact mills. From the primary crushers the rock is screened and conveyed to the secondary crusher, where crushing is completed. Typical crushers are hammer mills that reduce the rock to a maximum of 3/4 in.[1/]

In the wet process, the wet, ground material is pumped in the form of a slurry containing about 40% water into a series of large mixing tanks and from these it is pumped into the kiln. In the dry process, the dry, ground, raw material is carried by a conveyor to the storage bins, and from the bins it is fed into the kiln.

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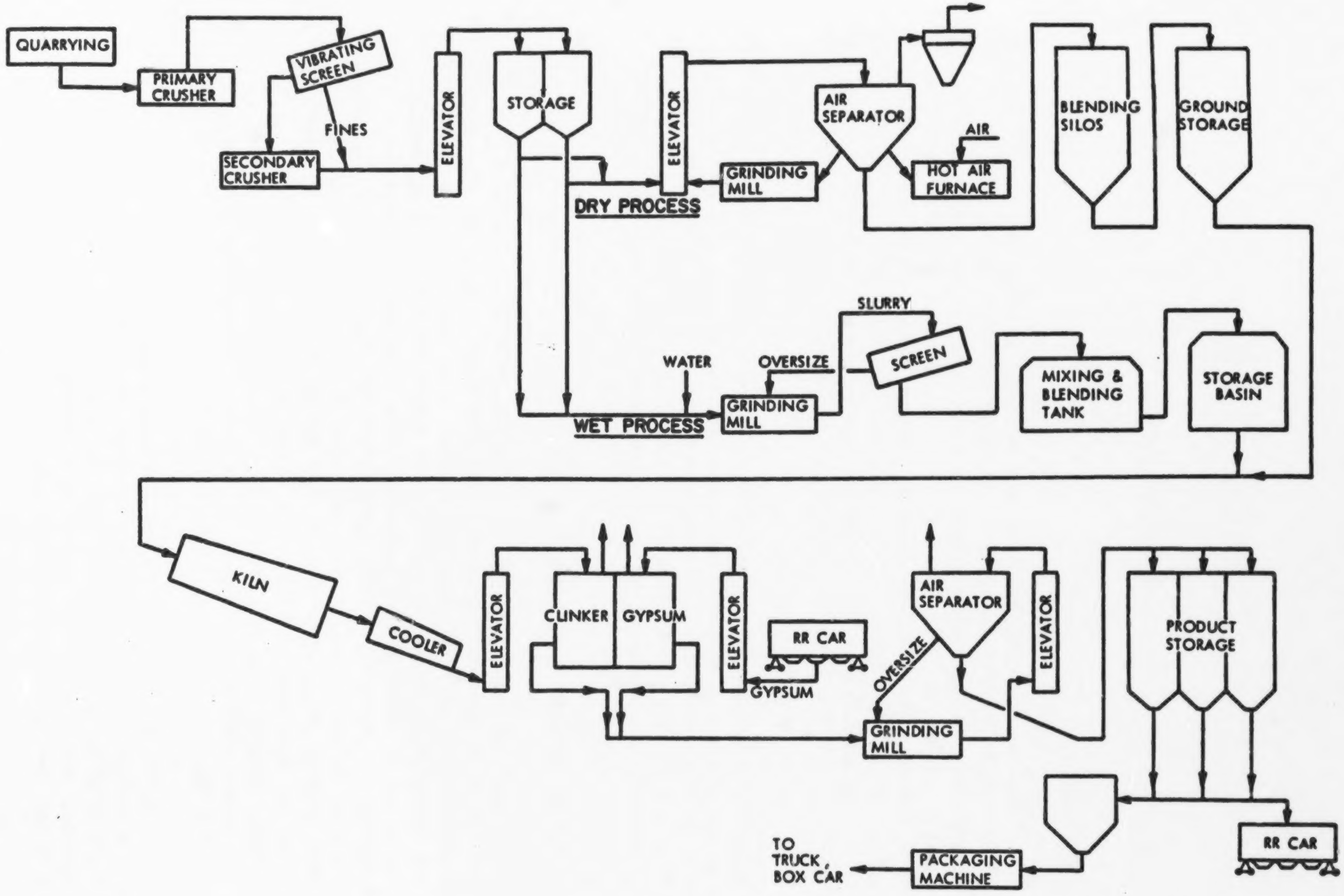

Figure 10-1 - Sources of Dust Emissions Cement Plants

The raw materials, either in the wet or dry form, enter the kiln at the top end and contact the combustion gases which pass through the kiln counter-current to the material. As the kiln revolves, the raw materials fall down toward the clinkering zone, having been first dried by the hot gases, and then having the carbon dioxide driven off from the calcareous materials. The partially fused product or cement clinker passes from the lower end of the kiln to the clinker cooler where some of its heat preheats air going to the kiln. The clinker, with the addition of a little gypsum or water to regulate the setting time, is then ground in ball and tube mills to the requisite fineness for a finished product.

10.3 EMISSION RATES FROM CEMENT MANUFACTURING PLANTS

The major source of particulate emissions in cement plants is the calcining kiln. Dust is generated in kiln operations by the grinding and tumbling action within the kiln, by the liberation of gases during calcination which tends to expel particles into the gas stream, and by the condensation of material that is volatilized during passage through the kiln. Volatilization and condensation generally produce smaller particles than the mechanical processes.

The principal secondary sources in the cement industry are dryers and crushers. Dust emissions from dryers result from abrasion of the material being processed and carry over from the kiln. The magnitude of the dust problem from crushing operations depends on the type and moisture content of the raw material, and the characteristics and type of crusher.

10.3.1 Cement Kilns

Variations in kiln operation and design can contribute to the nature and quantity of emissions. The types of kilns used in the dry and wet processes are discussed in the following sections.

10.3.1.1 Dry-Process Kiln Systems: Dry-process kiln systems consist of (1) short rotary kiln with or without a waste-heat boiler, (2) rotary kiln with suspension preheater, (3) long rotary kiln with or without a built-in preheater, (4) "Lepol" kilns with double gas flow (semi-dry process), (5) pit kiln, and (6) traveling sintering grate kiln. Rotary kilns are used in the United States, and almost all new plants utilize long kilns with chain or other preheating systems.

10.3.1.1.1 Rotary kiln: The rotary kiln used in most plants is a steel cylinder with a refractory lining. The kiln feed is introduced into the upper end of the revolving sloped kiln. During the passage through the kiln, the raw materials are dried, calcined, and heated to a point of incipient fusion. The combustion gases pass through the kiln counterflow to the material, and leave the kiln, along with carbon dioxide driven off during calcination, at temperatures of 300-1800°F, depending on kiln length and the process used.

10.3.1.1.2 Rotary kiln with ascending gas heat exchanger: In dry-process rotary kilns with suspension-gas heat exchanger the dry raw material powder is fed into the first and highest of four vertically arranged stages of a cyclone located ahead of the kiln. While passing through the four stages of the cyclone, the classifying action of the cyclone suspends the fines of the raw material in the waste gases and the dust beyond the heat exchanger is 90% < 10 μ. Collection of this dust is difficult.

10.3.1.1.3 "Lepol" furnace with double gas flow: In the "Lepol" kiln with double gas flow, the clinker formed in a drum or on a plate from raw material powder and water is dried initially on a traveling grate by the waste gases of the rotary kiln, then heated and partially calcined and subsequently transformed into clinker in the rotary kiln.[2]

The waste gases of the rotary kiln are first drawn upward into the "hot chamber" through the layer of clinker on the grate, preliminary dust removal being effected in an intermediate dust removal installation (cyclone). The waste gases are then transported by means of a blower into a drying chamber where these gases are again drawn through the moist layer of clinker. During this process, the residual dust is almost completely retained in the still moist layer of clinker. The gases are discharged at a temperature of about 200°F through a stack of a second blower.

High dust-emission levels from these units may have the following causes:

a. Damaged grate units so that the gases are not filtered in passing through the grate.

b. Too rapid heating of the granulate. Feed material which has been heated too quickly, or is too dense, has a tendency to burst. In order to obtain granulate as resistant to heat as possible, the raw-material powder and water distribution on the granulating plate should be uniform. Temperatures in the drying and in the hot chambers must be continuously controlled, and frequent inspection of the separation well between "hot" and drying chamber is also required.

c. Maladjusted suction fans. Fans must be adjusted so that vacuum in the hot chamber is always higher than the vacuum in the second chamber. All gases will then undergo intermediate dust separation in the moist layer of granulate of the drying chamber.

10.3.1.2 Wet-Process Kiln Systems: Two basic types of wet-process kilns are in use in the U.S.: (a) short kilns with waste-heat boilers, and (b) long kilns with internal chain preheaters.

10.3.1.2.1 Rotary kiln with built-in units: In kilns with chain baffles in the preheating area, the chains serve to distribute the raw paste over a large surface. The effect of the chains increases with their number. Their position and length in the rotary kilns are arranged so that the clinker material still contains about 10% moisture upon leaving the last chain. This percentage is necessary so as not to overheat the chains.

In preheated kilns, chambers ahead of the chain area are arranged crosswise and rotate with the kiln. Through a suitable arrangement of the inlet and outlet apertures of the chambers, the paste flowing along the bottom of the kiln enters the chambers and comes in close contact with waste gases flowing through the chambers.

The dust emission from wet-process rotary kilns is highly dependent on variations in kiln operation. If the waste-gas temperature becomes too high, which may be the case when there are variations of the calorific value of the fuel or through increase of the kiln output, the raw paste may lose its entire water content in the chain area. Any granulate formed is reduced to dust by the last of the chains, and this dust is then carried out of the kiln by the waste gases.

10.3.1.2.2 Rotary kilns with paste dryers: In wet-process rotary kilns with paste dryer (concentrator, calcinator), the raw material paste enters the slowly rotating grate drum through ducts. The drum contains baffles and is arranged ahead of the kiln. The hot waste gases of the rotary kiln enter the grate drum from below, heat the baffles and thereby dry the raw material paste into granulate. Additional drying, as well as calcination and sintering into clinker, takes place in the rotary kiln.

Heat economizers (e.g., scoops) in the kiln and particularly at the inlet increase the production of dust. The kiln-inlet chute should extend very close to the lining of the kiln so that the high-velocity waste gases will not entrain the fines and return them to the paste dryer, which will increase the dust content of the gas.[2]

10.3.2 Effect of Feed Composition on Dust Emission

Different types of feed composition also affect emission rates. One of the most important causes of dust emissions is the way in which gases are liberated and expelled from the raw feed during calcination. Some raw materials remain relatively calm while the liberated gases escape; others appear to expand and explode, throwing the material into the gas stream. This may explain why some wet-process plants have a higher dust loss than some dry-process plants.1/

10.3.3 Secondary Sources in Cement Manufacture

Particulate emissions also originate from dryers, coolers, grinding, and packing operations. Meager data exist on emissions from these sources.

10.3.4 Summary of Emission Rates

The emission factors for individual sources and total particulate emissions are summarized in Table 10-1. A statistical analysis of emission-factor data for wet- and dry-process kilns indicated that the differences between the average emission factors for each process are not statistically significant. A single emission factor was therefore used for kilns. The emission factor, 166 lb/ton, is the geometric mean of 31 items of data.

Emission-factor data are meager for the secondary sources (i.e., dryers, mills, elevators). Reference 3 indicates that in dry-process plants emissions from secondary sources are about 40% of kiln emissions, while in wet-process plants they are about 15% of kiln emissions. On this basis, emission factors of 67 and 25 lb/ton were selected for secondary sources in dry- and wet-process plants. Total emissions from these secondary sources were calculated with the assumption that the average operating efficiency of control equipment and the percentage of production capacity controlled were the same as for kilns. Information collected during a survey of the cement industry indicated that bag filters are used extensively on these sources. Therefore, the assumption of the same degree of net control as for kilns is not believed to be unreasonable.

Total particulate emissions, as shown in Table 10-1, currently total 934,000 tons/year.

TABLE 10-1

PARTICULATE EMISSIONS
CEMENT INDUSTRY

Source	Production	Emission Factor (e_f)	Efficiency of Control (C_c)	Application of Control (C_t)	Net Control ($C_c \cdot C_t$)	Emissions (tons/year)
Kilns	74,600,000	167	0.94	0.94	0.88	745,000
Grinders, Dryers, elevators, etc.						
Wet Process	43,600,000	25	0.94	0.94	0.88	65,000
Dry Process	31,000,000	67	0.94	0.94	0.88	124,000
					Total for Cement	934,000

10.4 CHARACTERISTICS OF CEMENT PLANT EMISSIONS

The chemical and physical properties of cement plant effluents are summarized in Table 10-2. Mechanical, volatilization, and condensation processes produce the particulate emissions. Volatilization and condensation generally produce smaller particles than the mechanical processes. The mass median size of particulate emissions from kilns is 8.5 μ and the geometric deviation is 4.1.

10.5 CONTROL PRACTICES AND EQUIPMENT FOR CEMENT PLANTS

10.5.1 Control Practices

Dust can be adequately arrested in the cement industry by proper selection of dust control equipment. Dust emissions as low as 0.03 to 0.05 grain/scf have been obtained in newly designed well-controlled plants.1/ Table 10-3 gives ranges of dust emissions for various combinations of control devices.1/ An emission level of 0.1 grain/scf is probably the value needed to preclude nuisance complaints from nearby residents.3/

The hot kiln gases are the main source of emission and they present a major problem because gas volumes are large; they contain acid gases such as H_2S and SO_2, varying amounts of H_2O, and a temperature range usually above 500 or 600°F.4/ A kiln producing 20 tons/hr of cement clinker will produce about 240,000 lb/hr of exit gases, or about 92,000 acfm.5/

10.5.2 Control Equipment

10.5.2.1 Multicyclones: Although a number of types of dust collectors are used in the cement industry, only the high-efficiency collectors such as the electrostatic precipitator and fabric filter, sometimes used in series with inertial collectors, effectively collect fine dust. The multicyclones alone are not an acceptable means of reducing dust emission from the kiln to the atmosphere.

Multicyclones, when preceding other control equipment, can be expected to scalp off about 70 wt. % or all of the coarser particles.

10.5.2.2 Electrostatic Precipitators: In a wet-process plant the performance of an electrostatic precipitator is greatly enhanced by the extra water vapor present in the exhaust gases from the slurry. Dry-process kilns do not have this water in the feed and often it is necessary to add it as an aid to precipitator operation.6/

TABLE 10-2

EFFLUENT CHARACTERISTICS - CEMENT MANUFACTURE*

A. Particulate (Part I)

Source	Particle Size	Solids Loading	Chemical Composition	Particle Density	Electrical Resistivity	Moisture Content	Toxicity
Cement Plant a. Kiln	Wagner Turbidimeter 15.5 < 5, 43 < 10 64 < 20, 88 < 40 BAHCO Analysis: 25-32 < 5 Average 30 < 5 40-52 < 10 Average 47.6 < 10 55-73 < 20 Average 66.7 < 20 67-89 < 40 Average 80.5 < 40 (Also see Figure 10-2) mass median - 8.5 $\sigma = 4.1$	Dry Process 1-17 (stack conditions) Average 6.4 Wet Process 1-14 (stack conditions) Average 5.7	CaO: 39-50; SiO_2: 9.8-19; Fe_2O_3: 2-11; Al_2O_3: 2-8; K_2O:2-8; Na_2O: 0.9-1.1; MgO: 1.3-2.5	2.6-3.2	See Figures 10-3, 10-4, 10-5 and 10-6 for detailed data		N.T.
b. Dryer							
(1) Standard drum	40-70 < 10^{+}	$13\text{-}40^{+}$					
(2) Quick dryer	50-70 < 10^{+}	$13\text{-}100^{+}$					
(3) Unspecified type		5-40 (stack conditions)					
c. Cement Cooler (clinker dust)	BAHCO Analysis 3-6.5 < 5 Average 4.7 < 5 4.8-12 < 10 Average 7.9 < 10 10.4-18.1 < 15 Average 12.4 < 15			3.6-3.9			

A. Particulate (Part II)

Source	Solubility	Wettability	Hygroscopic Characteristics	Flammability or Explosive Limits	Handling Characteristics	Optical Properties
Cement Plant a. Kiln	CaO - s. H_2O CaO, SiO_2, Fe_2O_3, Al_2O_3, TiO_2 - s. 10% HCl		Will absorb H_2O		Angle of repose 39 degrees (Portland Cement)	

+ = German data.

* See Coding Key, Table 5-1, Chapter 5, page 45, for units for individual effluent properties.

TABLE 10-2 (Concluded)

B. Carrier Gas

Source	Flow Rate	Temperature	Moisture Content	Chemical Composition	Toxicity	Corrosivity	Odor	Flammability or Explosive Limits
Cement Plant								
a. Kiln	Dry Process a. 34-300 (stack conditions) b. 94-614 (stack conditions) Wet Process a. 72-445 (stack conditions) b. 166-570 (stack conditions)	Dry Process 150-845 Wet Process 290-650	Dry Process 1-2 Wet Process 20-40	CO_2, steam, O_2, N_2, small amounts SO_2, NO_x, CO, and polysulfides Typical Analysis CO_2: 17-25 O_2: 1-4 CO: 0-2 N_2: 75-80	N.T.	Gases contain 0-40% steam and will corrode dead spots in piping		
b. Dryer								
(1) Standard drum	a. -- b. 26-64$^+$ (stack conditions)	158-302$^+$	Dew point: 104-158$^+$					
(2) Quick dryer	a. -- b. 16-48$^+$ (stack conditions)	158-302$^+$						
(3) Unspecified type	a. 10-80 (stack conditions) b. --		5-12					

+ = German data.

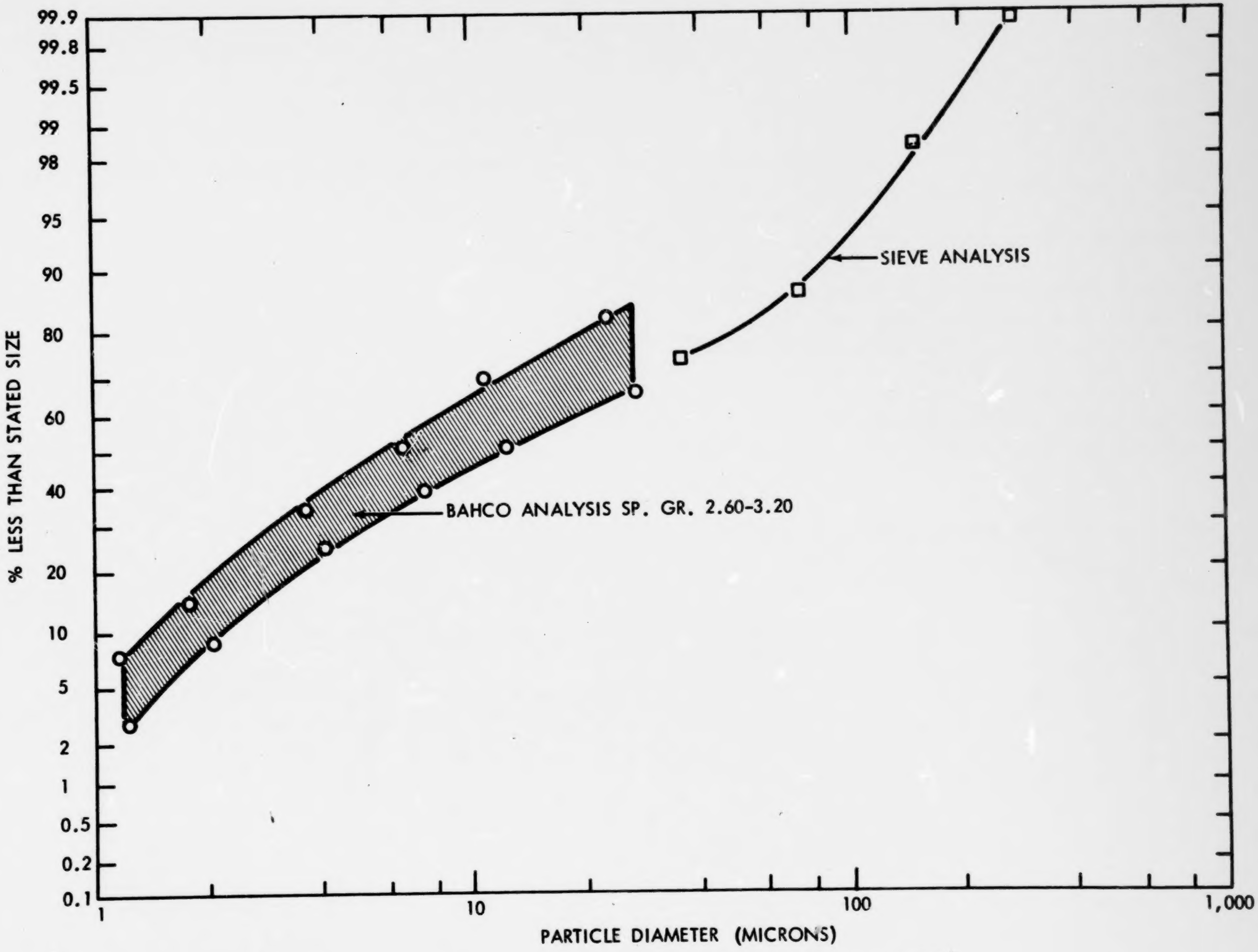

Figure 10-2 - Typical Particle Size Range of Cement Kiln Dust[10]

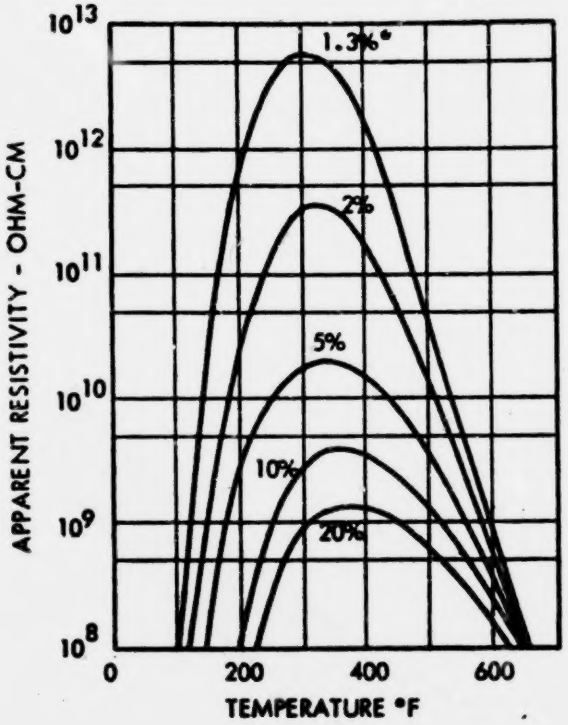

Figure 10-3 - Resistivity of Cement Kiln Dust Under Varying Conditions of Temperature and Moisture in Gas11/

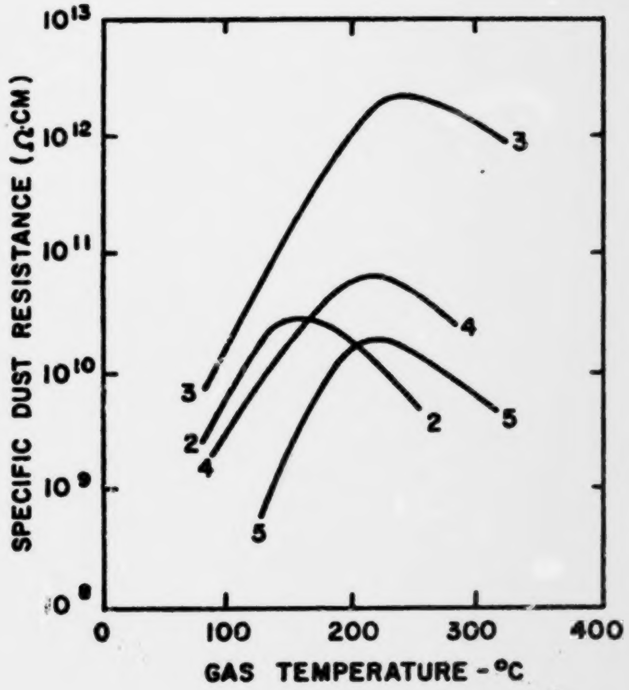

Figure 10-4- Dependence of Specific Electrical Dust Resistance on Gas Temperature for Various Dusts12/

Curve 2 originated from a rotary cement kiln of the older type, operated by a dry process.

Curve 3 pertains to a rotary cement kiln with heat exchanger.

Curve 4 cement dust rotary kiln with concentrator.

Curve 5 cement dust rotary kiln with sludge injection.

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* Figure shows percent water vapor by volume.

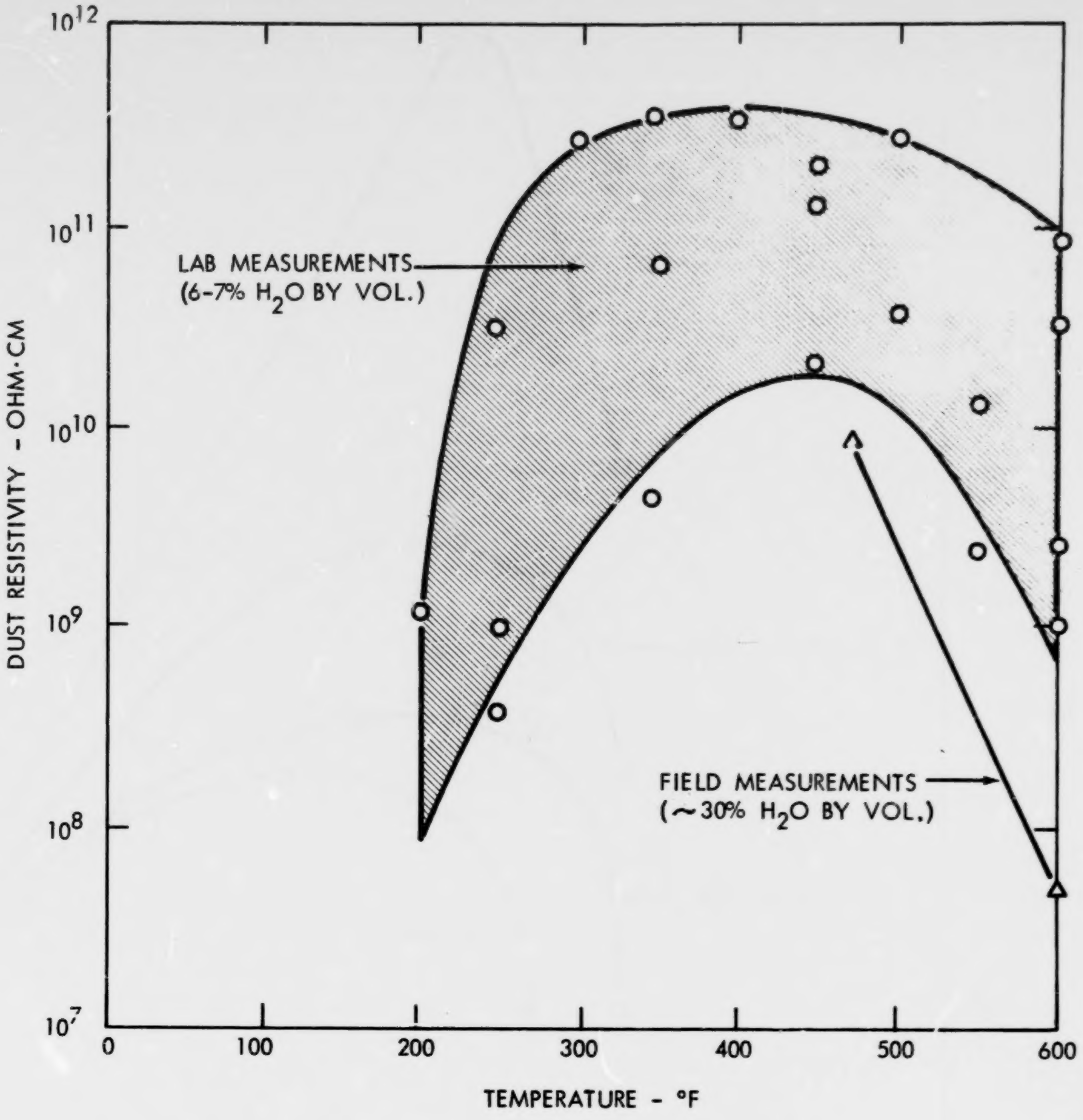

Figure 10-5 - Typical Laboratory and Field Resistivities of Cement Kiln Dusts[10]

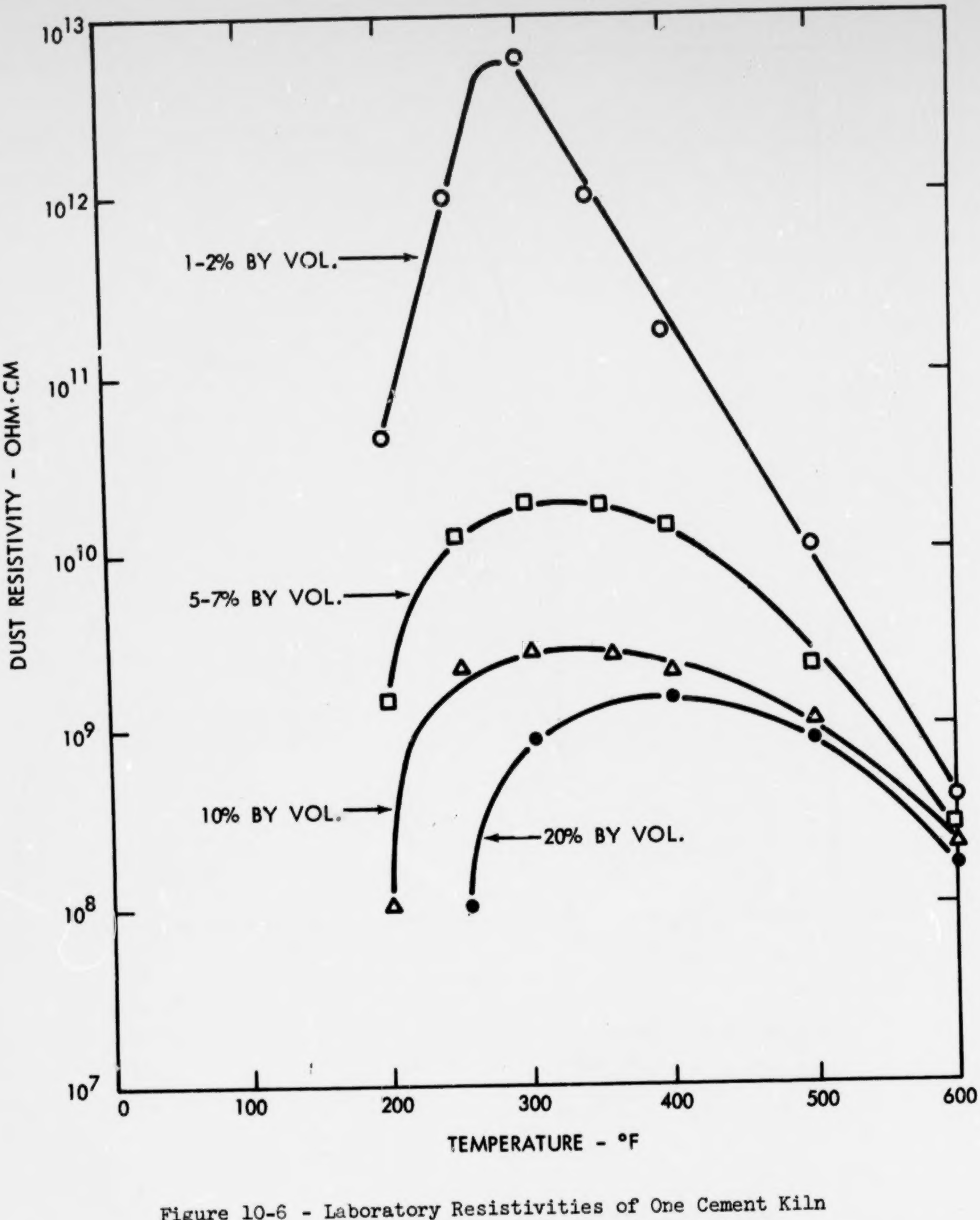

Figure 10-6 - Laboratory Resistivities of One Cement Kiln Dust Sample for Various Gas Moisture Contents[10]

TABLE 10-3

RANGES OF DUST EMISSIONS FROM CONTROL SYSTEMS SERVING DRY- AND WET-TYPE CEMENT KILNS1/

Source	Type of Dust Collector	Range of Dust Emissions from Collector	
		grain/scf[a/]	lb/ton of Cement
Kiln-dry type	Multicyclones	1.55 - 3.06	26.2 - 68.6
	Electrical precipitators	0.04 - 0.15	1.7 - 5.7
	Multicyclone and electrical precipitators	0.03 - 1.3	0.6 - 29.4
	Multicyclone and cloth filter	0.039	0.7
Kiln-wet type	Electrical precipitators	0.03 - 0.73	0.52 - 9.9
	Multicyclone and electrical precipitators	0.04 - 0.06	4.3 - 24.2
	Cloth filter	0.015	0.35

[a/] Grains/scf - Grains/standard cubic foot of gas corrected to 60°F and 1 atm. pressure.

The operation of electrostatic precipitators has not been entirely satisfactory in the past because of decreasing efficiency over extended periods due to the effects of the cement dust on the high voltage components.[4] Also, when kilns have been shut down and then restarted, it may be necessary to by-pass the electrostatic precipitator for periods up to 24 hr. because of the danger of explosion from the presence of combustible gas or coal dust.

The total installation cost of an electrostatic precipitator is shown to be as high as 400% of the purchase cost in the HEW publication AP-51.[7] It is reported that this figure should be somewhat higher based on costs frequently experienced in the cement industry.[8] Recent cost data for electrostatic precipitators used in the cement industry indicate that the installed cost for precipitators having efficiencies of 99.0 - 99.9% ranges from $1.00 to $3.50/acfm with an average of $1.80/acfm.[10]

10.5.2.3 Fabric Filters: Fiberglass baghouse filters have had much success in controlling kiln emissions. Bag life averages 2 years or more.[4] A big plus in baghouse installations is the fact that duct designs are simple and uncomplicated, requiring little study for the flow of gases when compared with the frequently complicated model studies necessary for good gas-flow patterns in the electrostatic-type dust collector.[4]

Moisture condensation in glass-fabric filters can present problems. However, dew point temperatures are normally avoided by proper application of insulation to ducting, etc., and by proper operation to avoid condensation.

The simplicity of design and operation of the fiberglass filter system, which lowers the cost, is balanced to some extent by increased fan power needed to overcome pressure drop across the baghouse. Many baghouses operate with a pressure drop of 3 to 7 in. of water. Sample data for fiberglass baghouses are given in Reference 9.

The total installation cost of fabric filters is shown to be as much as 400% of the purchase cost in HEW Publication AP-51.[7] This figure is claimed to be in line with cement industry experience.[8]

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CHAPTER 11

FOREST PRODUCTS INDUSTRY

11.1 INTRODUCTION

The forest products industry as considered here encompasses forestry, sawmill, plywood, particleboard, hardboard, and pulp mill operations. Emissions from this industry are highly variable, and range from dust resulting from logging operations to particulates emitted from lime kilns in pulp mills. Particulate emission sources include wood-waste incinerators, plywood dryers, sawmill planers, sanders, recovery furnaces, and power boilers. Figure 11-1 presents a composite flow diagram for the forest products industry.

Manufacturing processes, particulate emission sources, particulate emission rates, effluent characteristics, and control practices and equipment associated with this industry are discussed in the following sections.

11.2 FORESTRY OPERATIONS

Forestry operations center around timber cutting. Trees are harvested by logging crews and transported to sawmills, plywood plants, etc., for subsequent processing. Logs are transported by truck, floated down a river, or towed by tugs in the form of "log booms or rafts."

11.2.1 Emission Sources and Rates

Apart from the dust generation resulting from logging operations, a major source of air pollution in forestry operations is the burning of wood residues. Common methods of disposal include open burning and incineration in a "wigwam" burner. The diversity of reasons for burning and the large land areas involved lead to significant pollution from these practices.

Determination of the emission potential of slash burning is difficult because accurate estimates for total acreage or fuel loading for range burning are not available. Particulate emissions from slash burning have been estimated by two agencies of the U. S. Department of Agriculture.[1] The Forest Service reported an estimate of 17 million tons of particulate matter produced by "Prescribed Fires" in the United States in 1967. Six million tons of this total are attributed to slash burning. Slash burning, primarily practiced in the western United States, is employed to reduce the flammability of heavy concentrations of slash left after timber cutting.

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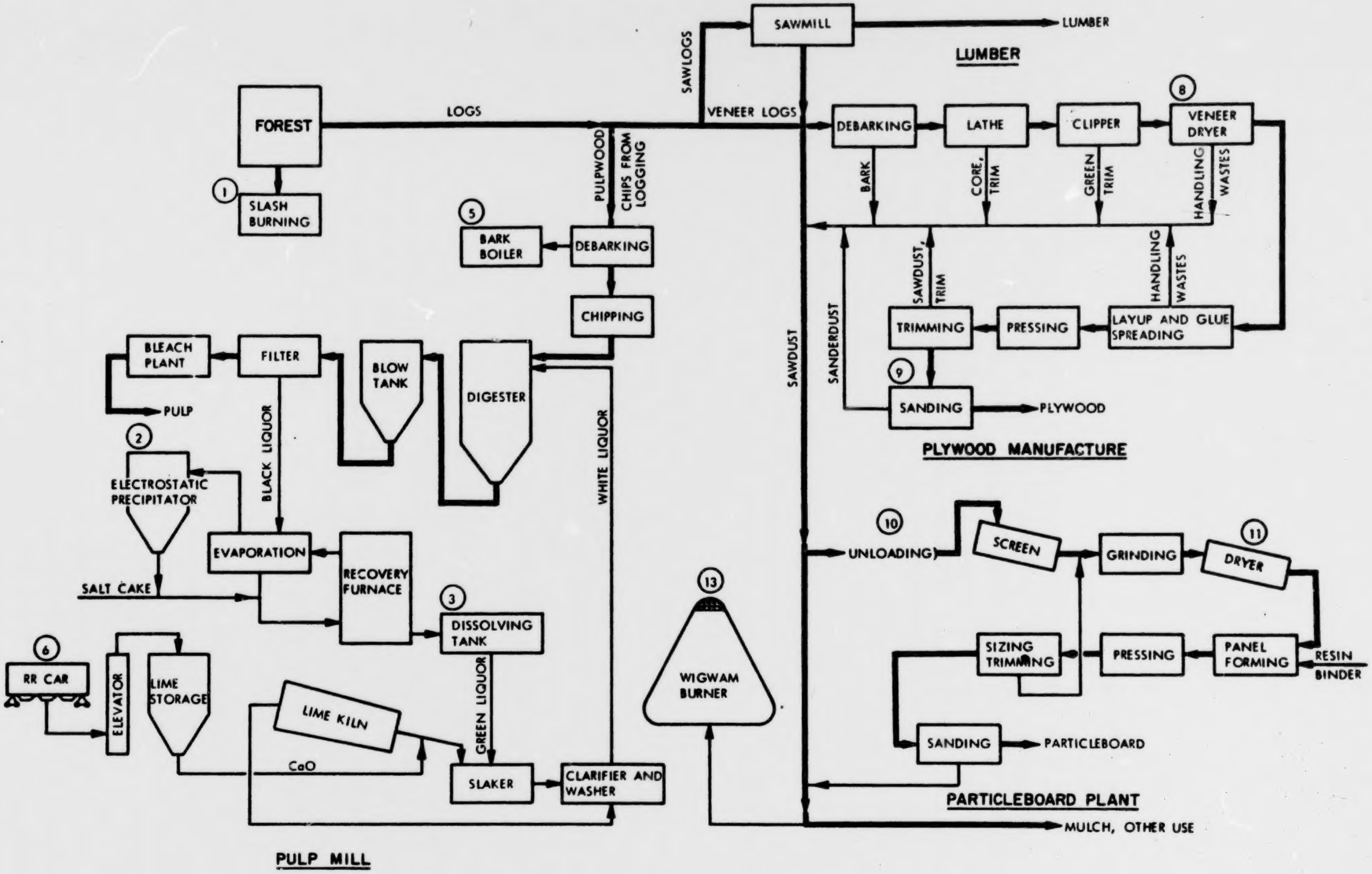

Figure 11-1 - Composite Flow Diagram - Forest Products Industry

Prescribed burning in the eastern United States is used primarily to remove accumulated litter on the forest floor and the 11 million tons emitted are not included in the slash-burning category. The Forest Service also estimates that the "fuel consumed in the west" is 21 x 10^6 tons per year.

The Soil and Water Conservation Research Division estimates that 25 million tons of logging debris are burned each year and that 6.5 x 10^6 tons of particulates are produced by prescribed burning in the forests.[2]

As shown in Table 11-1, emissions from slash burning are taken to be 6 million tons in accordance with the estimate of the Agriculture Department. Emissions from vehicle traffic on logging roads were not estimated.

11.2.2 Effluent Characteristics

Data on effluent characteristics from slash burning are meager. Research is being conducted on the subject at Oregon State University, Washington State University, and the University of Washington.

Field tests on slash burning conducted by the University of Washington investigators have resulted in the following observations:[3]

1. Ground-level particulate increased to nearly 10 times the background immediately downwind from a broadcast burn. The particulate in the smoke plume in the fire vicinity reduced visibility to 0.5 km., but at a distance of 19 km. from the fire the visibility had increased to the level found over Seattle.

2. Similarly, high CO and CO_2 concentrations found at the fire site decreased rapidly to ambient conditions in horizontal and vertical directions.

3. Hydrocarbon analyses of the gas samples revealed low concentrations of 25 components, the most significant of which appeared to be the low molecular weight hydrocarbons and alcohols including ethylene, ethane, propene, propane, methanol, and ethanol. Several unsaturated components were found, but the quantities were relatively low.

The results of the study of broadcast fires, plus those on pile and laboratory fires, suggest that broadcast fires can be modeled in the laboratory with respect to burning characteristics, gaseous and particulate emissions from different fuel density, packing, quality, and method of ignition. Furthermore, that study indicates that the air pollution aspects of slash burning can be minimized by establishing a high energy fire with a strong convection column under conditions favorable for rapid atmospheric dispersion.

TABLE 11-1

PARTICULATE EMISSIONS
FOREST PRODUCTS INDUSTRY

Source	Quantity of Material	Emission Factor	Efficiency of Control C_c	Application of Control C_t	Net Control $C_c \cdot C_t$	Emission (tons/yr)
I. Slash Burning	23,000,000 tons/yr					6,000,000
II. Wigwam Burners	27,500,000 tons/yr	10 lb/ton				132,000
III. Chemical Pulp Mills						
A. Kraft Process	24,300,000 tons pulp					
1. Recovery furnace		150 lb/ton	0.92	0.99	0.91	164,000
2. Lime kiln		45 lb/ton	0.95	0.99	0.94	33,000
3. Dissolving tanks		5 lb/ton	0.90	0.33	0.30	42,000
B. Sulfite Process						
1. Recovery Furnace	1/3 of 2,500,000 tons pulp	268 lb/ton	0.92	0.99	0.31	10,000
C. N.S.S.C. Process						
1. Recovery furnace	1/3 of 3,500,000 tons pulp	24 lb/ton	0.92	0.99	0.91	1,000
2. Fluid bed reactor	15% of 3,500,000 tons pulp	533 lb/ton	0.70	1.00	0.70	42,000
D. Bark Boilers	32,000,000 tons pulp					82,000
			Total from Chemical Pulp Mills			374,000
IV. Plywood, Particleboard Hardboard	1,500,000,000 sq. ft. plywood/yr					
A. Boilers		2.6 lb/ton burned				3,000
B. Cyclones		$45 \frac{\text{dry tons}}{\text{MM sq. ft., plywood}}$				67,000
C. Veneer Dryers		250 lb/MM sq. ft., plywood				4,000
						74,000
			Total for Forest Products Industry			6,580,000

Available data on the chemical and physical characteristics of effluents from forestry operations are summarized in Table 11-2.

11.2.3 Control Practices and Equipment

The various forestry operations that emit particulate matter, which include slash burning and incineration, do not lend themselves to the use of control equipment. Although some considerations of burning methods and meteorological conditions would undoubtedly influence these emissions, these factors do not fall in the category of control equipment.

11.3 SAWMILL OPERATIONS (LUMBER PRODUCTION)

The sawmill or lumber industry includes production of lumber, shingles and shakes, posts and pilings, and some lumber remanufacture and planing mills. Operations include debarking, sawing, and planing.

11.3.1 Emission Sources and Rates

The basic lumber production processes create few pollutants. Sawing and planing equipment generate wood wastes--sawdust, shavings--in particulate form. Planers usually have effective containment of this waste; but saws are seldom designed to contain and control fine particles, and wood dust emissions occur.

Collecting, transferring, and processing wood wastes for by-product markets or incineration cause significant particulate emissions because of the huge volume of the material.

Kiln drying of lumber probably does not create hydrocarbon emission, although this process has not been adequately studied.

Incineration of sawmill wood and bark wastes is the main air contaminant source. The "wigwam"-type burner is one common device used for this purpose. Reference 4 reports on a study of "wigwam" burners in the Pacific Northwest. Average temperature of the gases leaving the burner was 485°F, which is considerably below the 600-900°F temperature range recommended for smoke-free operation. Improving the combustion efficiency would reduce emissions from these burners.

Emissions from "wigwam" burners associated with sawmills are included in the 1.32 x 10^5 tons/year shown for these burners in Table 11-1.

TABLE 11-2

CHARACTERISTICS OF EFFLUENTS FROM FOREST PRODUCTS INDUSTRY‡

A. Particulate (Part I)

Source	Particle Size	Solids Loading	Chemical Composition	Particle Density	Electrical Resistivity	Moisture Content	Toxicity
Forest Products Industry							
1. Forestry operations							
a. Slash burning		950-1,510* (dependent on location, wind direction and stage of fire)	Alkanes, alkenes, alcohols, ketones, essential oils, fly ash				
2. Sawmills							
a. Planers	Fine sawdust						
b. Wigwam burner	Microscope: 24 < 2	0.004-0.61 Average: 0.17 (corrected to 12% CO_2)					
3. Plywood plant							
a. Incineration (see wigwam burner)							
b. Veneer dryer			Hydrocarbons				
c. Sander	Drum sander; Bahco analysis, 5.2 <5, 18 <10, 35.5 <20, 93.1 <40 Optical microscope: Mean count size, 22		Sawdust, sander dust				
d. Pressing machine			Phenolic resin				
4. Particleboard plant							
a. Incineration (see wigwam burner)							
b. Dryer							
c. Pressing machine			Formaldehyde-urea resin				
d. Sander (see plywood)							

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* Micrograms/cubic meter.

‡ See Coding Key, Table 5-1, Chapter 5, p. 45, for units for individual effluent properties.

TABLE 11-2 (Continued)

A. **Particulate** (Part I) (Concluded)

Source	Particle Size	Solids Loading	Chemical Composition	Particle Density	Electrical Resistivity	Moisture Content	Toxicity
Forest Products Industry							
5. Pulp Mills							
a. Kraft & Soda							
(1) Recovery furnace	50-85 < 2 Electron microscope count 16.8 < 0.5 53.2 < 1 30 > 1 Cascade impactor 50 < 0.95-1.1	3-8 (dry) Mean loading 3.8	Na_2SO_4: 14-90 Average - 80 Na_2CO_3: 2.6-73 Average - 11.2 NaCl: 0.6-14* Average - 2.3 Na_2S: 3.3-5.4 Average - 4.4 Carbon, Fly ash		See Figures 11-2 and 11-3 for detailed data	0.2-1.2 Average 0.45	N.T.
(2) Lime kiln	95 < 25	3-20	CaO, $CaCO_3$, Na_2CO_3, Na_2SO_4, $MgCO_3$, Fe_2O_3, Al_2O_3, SiO_2				N.T.
(3) Smelt dissolving tank	90 < 5	0.17-1.3	Na_2CO_3, Na_2S, Na_2SO_4				N.T.
(4) Boilers							
(a) bark-fired	Bahco Analysis 19-25 < 5 Average 22 < 5 34-48 < 10 Average 42 < 10 60-66 < 20 Average 63 < 20 70-79 < 40 Average 74 < 40	1.3-2.4 (dry)					
(b) oil-fired		0.04-0.4 (dry)					
(c) coal-fired		3.1-3.5 (dry)					
b. Sulfite.							
(1) Recovery furnace (magnesium bisulfite)		4.94					
(2) Boilers							
(a) bark-fired		1.32					
(b) oil-fired		0.04					
(c) coal-fired		3.1-3.5					
c. N.S.S.C.							
(1) Recovery furnace		4-8					
(2) Smelt dissolving tank		1.3					
(3) Boilers							
(a) bark-fired		2.05-2.4					
(b) oil-fired		0.04					
(c) coal-fired		3.19-3.5					

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* High NaCl content due to seawater immersion of logs.

TABLE 11-2 (Continued)

A. Particulate (Part II)

Source	Solubility	Wettability	Hygroscopic Characteristics	Flammability or Explosive Limits	Handling Characteristics	Optical Properties	Odor
Forest Products Industry							
1. Forestry operations							
a. Slash burning b. Wigwam burner							
2. Sawmills							
3. Plywood plant							
4. Particleboard plant							
5. Pulp mills							
a. Kraft and soda							
(1) Recovery furnace	Na_2SO_4 - s. H_2O, glc. Na_2CO_3 - s. H_2O, s.s. al. NaCl - s. H_2O, glyc. s.s. al.		Hygroscopic		Agglomerates, corrosive	Sodium salts-white;char, fly ash - black	
(2) Lime kiln	Na_2CO_3 - s. H_2O, s.s.al. $CaCO_3$ - s. H_2O $MgCO_3$ - s. H_2O Na_2SO_4 - s. H_2O, glyc. s.s. al.						
(3) Smelt dissolving tank	Na_2CO_3 - s. H_2O, s.s. al. Na_2S - s. H_2O s.s. al.						

TABLE 11-2 (Continued)

B. Carrier Gas

Source	Flow Rate	Temperature	Moisture Content	Chemical Composition	Toxicity	Corrosivity	Odor	Flammability or Explosive Limits
Forest Products Industry								
1. Forestry operation								
a. Slash burning		900-1550		CO_2, CO, CH_4, C_3H_8 C_2H_4, C_2H_6, C_3H_6 N_2, O_2				
2. Sawmills								
a. Planers								
b. Wigwam burner	Avg. velocity at burner top, 600 ft/min	166-866 Avg. 485		O_2, N_2, CO, CO_2, and various gaseous products of wood pyrolysis				
3. Plywood plants								
a. Incineration (see wigwam burner)								
b. Dryer		296-334	Dew Point 108-133	Hydrocarbons, air				
c. Sander	a) 40-60*			Air				
d. Pressing machine				Phenolic resin (gas and vapor) air				
4. Particleboard plant								
a. Incineration (see wigwam burner)								
b. Dryer								
c. Pressing machine				Formaldehyde-urea resin, air (gas and vapor)				
d. Sander (see plywood)								

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* Actual cubic feet/min.

TABLE 11-2 (Continued)

B. Carrier Gas (Continued)

Source	Flow Rate	Temperature	Moisture Content	Chemical Composition	Toxicity	Corrosivity	Odor	Flammability or Explosive Limits
5. Pulp mills a. Kraft & Soda (1) Recovery furnace	(a) 20-568 (b) 278-568 Avg. 432**	270-650 avg. 350	20-40 Dew Point 135-180	Typical Orsat analysis CO_2 - 12.5 CO - 0.1 O_2 - 7.6 N_2 - 79.8 Minor components H_2S - 130-935 ppm ‡MM - 60-1,400 ppm (1-15 ppm new plants) ‡DS - 0-125 ppm SO_2 - 1-350 ppm	SO_2 - 5	Corrosive due to sulfur compounds	Malodorous	H_2S: upper limit in air, 45.5%; lower limit in air, 4.3% CH_3SCH_3: upper limit in air, 9.19%; lower limit in air, 2.23% CH_3SH: upper limit in air, 21.8%; lower limit in air, 3.9%
(2) Lime kiln	(a) 7-50 (b) 31-53** Avg. 44	400-900	400-600*** Avg.556	CO_2 - 16.5-22 CO - 0-0.7 O_2 - 0.3-5.1 N_2 - 77.1-78.4 Minor components H_2S: 0.08-0.23*** SO_2: 0-2.5*** MM, DS: 0-0.6***	SO_2 -5 irritant	Corrosive due to sulfur compounds	Malodorous	
(3) Smelt dissolving tank	(b) 45**	170-200	670***	SO_2: 0-0.05*** H_2S: 0.01-0.04*** MM, DS: 0.01-0.09*** N_2 balance	SO_2 - 5 irritant	Corrosive due to sulfur compounds	Malodorous	
(4) Boilers (a) bark-fired	(b) 96-125 Avg. 112**		654-868*** Avg. 774	CO_2, O_2, N_2, SO_2	SO_2 - 5 irritant	"		
(b) oil-fired	(b) 99-366** Avg. 218		336-1,240*** Avg. 739	CO_2, O_2, N_2, SO_2	SO_2 - 5 irritant	"		
(c) coal-fired	(b) 91.4-340** Avg. 204		245-908** Avg. 539	CO_2, O_2, N_2, SO_2	SO_2 - 5 irritant	"		

** Standard ft^3/air-dried ton.

*** Pound/air-dried ton.

‡ MM - Methyl Mercaptan.
DS - Dimethyl Sulfide.

TABLE 11-2 (Concluded)

B. Carrier Gas (Concluded)

Source	Flow Rate	Temperature	Moisture Content	Chem. Composition	Toxicity	Corrosivity	Odor	Flammability or Explosive Limits
b. Sulfite								
(1) Recovery furnace (magnesium bisulfite)	b) 463^{**}	509	$3,000^{***}$	CO_2, N_2, O_2, SO_2, H_2S, MM, DS	SO_2 - 5 irritant	Corrosive due to sulfur compounds	Malodorous	See above
(2) Boiler								
(a) bark-fired	b) $105\text{-}122^{**}$ Average 113		$780\text{-}910^{***}$ Average 833	CO_2, N_2, O_2, SO_2	"	"		
(b) oil-fired	b) $148\text{-}420^{**}$ Average 295		$505\text{-}1,430^{***}$ Average 1,000	"				
(c) coal-fired	b) $137\text{-}388^{**}$ Average 258		$367\text{-}1,040^{***}$ Average 730	"	"	"		
c. N.S.S.C.								
(1) Recovery furnace	b) $107\text{-}189^{**}$ Average 148	325-1100	$1,100\text{-}1,400^{***}$ Average 1,250	CO_2, N_2, O_2, SO_2, H_2S	"	"	"	
(2) Smelt dissolving tank	b) 45^{**}	200	670^{***}	H_2S, SO_2, MM, DS	"	"	"	
(3) Boilers								
(a) bark-fired	b) $59\text{-}68^{**}$ Average 63.5		454^{***}	CO_2, N_2, O_2, SO_2	"	"		
(b) oil-fired	b) 306-318 Average 310		$1,040\text{-}1,080^{***}$ Average 1,060					
(c) coal-fired	b) 288-317 Average 303		$757\text{-}802^{***}$ Average 778					

** Methyl Mercaptan.

*** Dimethyl sulfide.

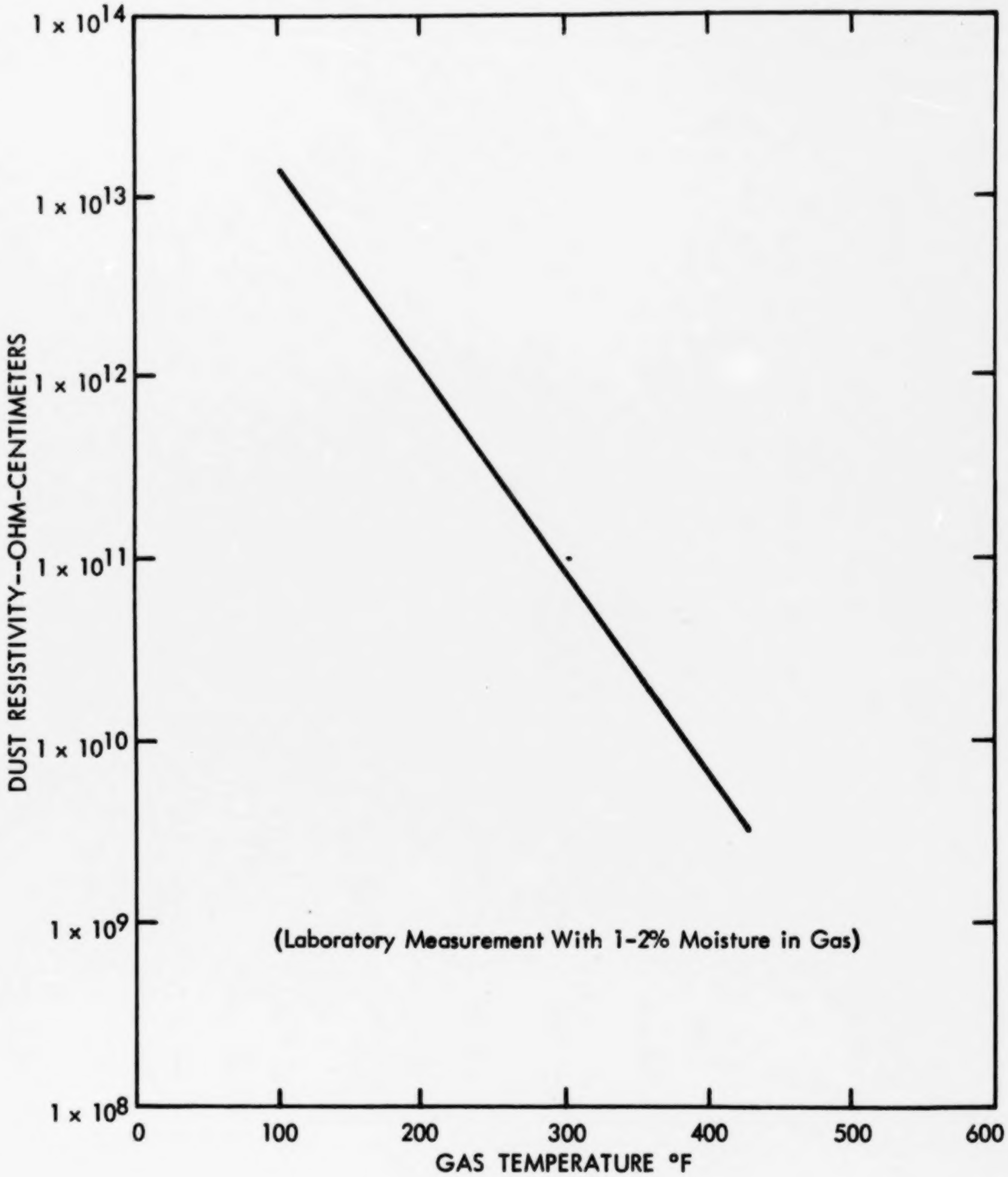

Figure 11-2 - Electrical Resistivity of Salt Cake[18]

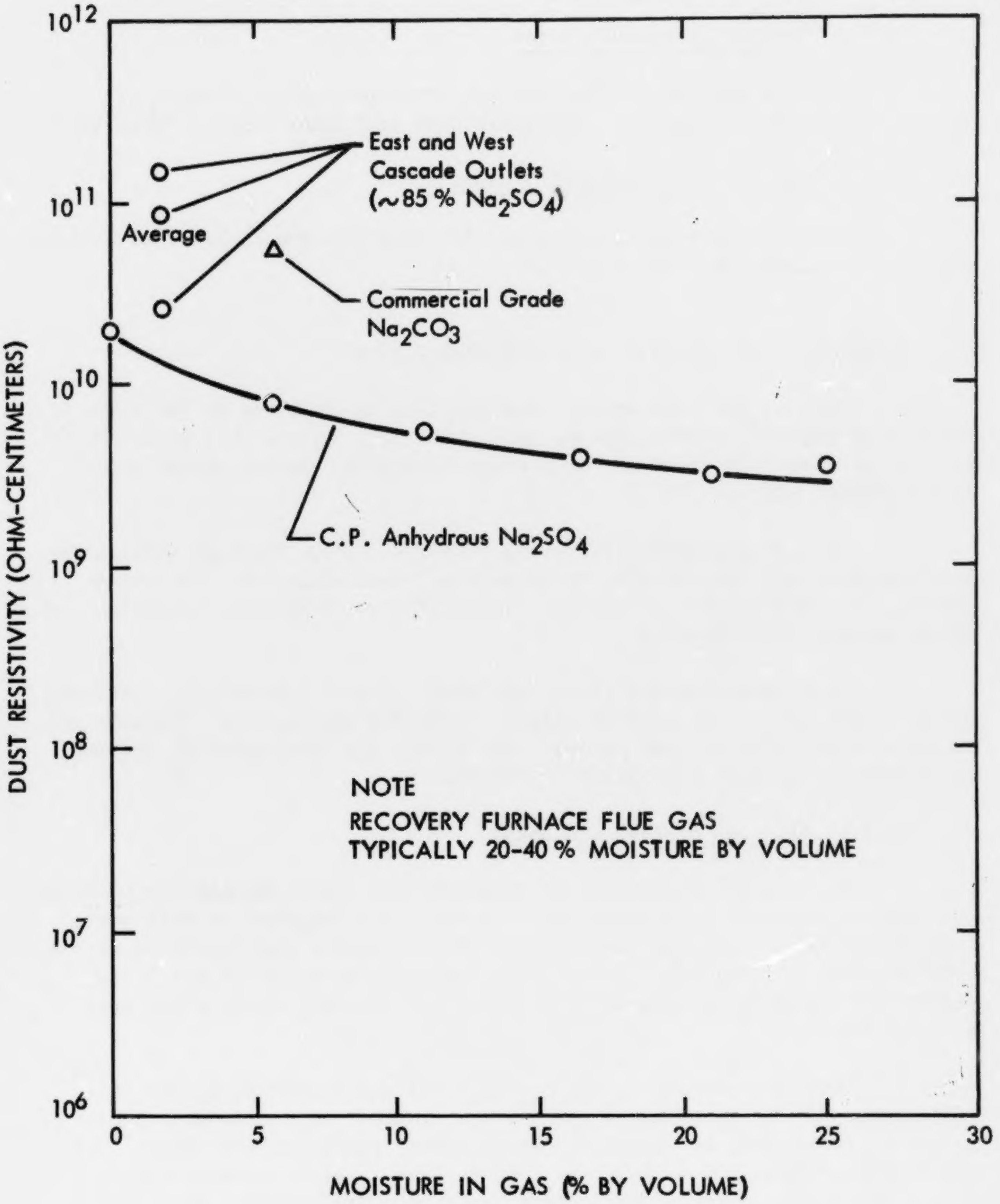

Figure 11-3 - Electrical Resistivity of Sodium Sulfate as a Function of Moisture in Gas at 300°F (Laboratory Measurements)[18]

11.3.2 Effluent Characteristics

Limited data were found for the effluent characteristics of emission sources in sawmills. Available data are summarized in Table 11-2.

11.3.3 Control Practices and Equipment

Comments on control practices for sawmills are included with those for plywood plants in Section 11.4.3.

11.4 PLYWOOD, PARTICLEBOARD, AND HARDBOARD PLANTS

Part of the wood wastes from sawmills is utilized in the manufacture of plywood, particleboard, and hardboard. Figure 11-1 presents typical process flow diagrams for plywood veneer and layout plants and a particleboard plant.

In the plywood manufacturing cycle, the logs first go through debarking, peeling, and clipping to produce a veneer material. Following drying, the veneer proceeds through layup and glue spreading, pressing, trimming, and final sanding.

In a particleboard plant, the waste wood is screened, ground, and dried in the initial processing steps. After the drying step, the material is mixed with resin to form panels. The panels are then pressed, trimmed and sanded to produce the finished product.

11.4.1 Emission Sources and Rates

Particulate pollutants in comparatively small amounts are produced in these processes. In plywood veneer plants, the disposal of wood waste creates the major emission problem. In plywood layout and finishing plants some emission sources also involve wood wastes. Incineration and boiler plants are the principal means of disposal and "wigwam" burners are used quite extensively.

Emission sources in a plywood layout and finishing plant, in addition to incinerators and power boilers, include veneer dryers, panel pressing operations, and sanders. Green veneer panels (50% moisture) are dried to less than 10% moisture in long enclosed heated chambers called ventilated veneer dryers. Two dryers are rarely ever alike. They emit a visible blue plume which is saturated with water vapor and loaded heavily with hydrocarbons.

Plywood pressing operations are another source of emissions. Phenolic resin loss to the atmosphere during pressing of panels may contribute to local air pollution problems. Overall emissions from this type of resin appear to be very minor although detailed data are not available.

Plywood sanding operations produce a large volume of sanderdust. Plywood is either produced as unsanded sheathing or it is sanded on either one side or two sides. Volume of sanderdust generated has been reported to vary from 33.3 to 99.5 tons/million sq ft of sanded plywood panels.5/

Emission sources at a particleboard plant include: (1) transfer operations, (2) drying operations, (3) pressing operations, (4) sanding operations, and (5) incineration.

The only waste material at particleboard-hardboard plants is sanderdust, as other wastes are recycled to the manufacturing process. Emissions from incineration of this material would be similar to those described for sawmills.

Particleboard plants purchase plywood trim, planer shavings, and sawdust, which includes small quantities of sanderdust, as raw materials. As the loaded trucks dump into receiving hoppers, considerable quantities of the fine particulate are carried into the atmosphere.

Particleboard and hardboard plants process "green" raw material through rotary kiln-like dryers. No data were found for emissions from these dryers.

Emissions of formaldehyde-urea resin during pressing operations have produced air pollution problems near particleboard and hardboard plants. The formaldehyde odor of the finished product is the main problem. The bulk of formaldehyde emission occurs during the high temperature (350°F) press which cures and sets the resin. It has been reported that at a press temperature of 350°F, and with a 1.8:1 molecular weight ratio of formaldehyde urea resin, 3% of the total solids will be leached as free formaldehyde. One percent would be emitted at a 1.2:1 mole ratio. The resin binder itself consists of approximately 10% of the total weight of particleboard and 6% in hardboard produced by the dry method.

Emissions from sanding operations would be similar to those discussed under plywood manufacture. After being sized in the trim saws, particleboard is sanded on two sides and the hardboard on one. The quantity of sanderdust generated depends on sanded depth and density of the board and has been reported to vary from 42.5 to 156 tons/million sq ft sanded.5/

Emission rates from these plants are summarized in Table 11-1. Limited data are available as these plants have not been thoroughly studied as air pollution sources.

11.4.2 Effluent Characteristics

Data on effluent characteristics from plywood, particleboard, and hardboard plants are limited. Table 11-2 summarizes information currently available. Dust from a drum sander is about 20 wt. % less than 10 μ.

11.4.3 Control Practices and Equipment

Emissions from these operations and from sawmills result primarily from steps producing sawdust or from incineration. Cyclones have wide application in the collection of sawdust but very little information is available on their design or operating efficiency. Baghouses can probably be used for the collection of this sawdust in many instances, but the pressure drop involved would be higher than for cyclones. Afterburners could be used on sources which emitted combustible vapors or mists.

11.5 PULP INDUSTRY

Characteristic air-pollution problems of the pulp industry are associated with the release of malodorous sulfur compounds and particulate matter. Pulp is made by either the sulfate (kraft), sulfite, semichemical, soda, or by a mechanical process. Most of the pulp produced in the United States is made by the kraft process. The sulfite process accounts for less than 10% of the pulp production.

11.5.1 Kraft Process

The chemical pulping process known as kraft pulping, employs a cooking liquor whose main ingredients are sodium sulfide and sodium hydroxide in solution. High-pressure digestion of wood chips dissolves the liquor in wood, and frees its cellulose fiber for use as pulp. A typical batch digester will reach temperatures of 350°F and pressures of 110 lb/sq in., and take 3 hr. for a cook. The full cooking pressure is used to blow the digester contents into the blow pit, ending the cooking cycle.

More recently, new mills have been utilizing continuous digestion because of improved control over the cooking cycle and hence a better quality of pulp. Wood chips, liquor and steam are supplied continuously at one end of the digestor, while the finished pulp and spent liquor are removed at the other end. Continuous digesters are also used to produce a low-grade pulp from sawdust.

As shown in Figure 11-1, diluted pulp from the blow pits is separated from the spent liquor by filtration and washing. The spent cooking liquor at this point is black from the lignin, waste fibers, and dissolved sulfide salts--and hence called "black liquor." Vitally important to the economics of the kraft process is the recovery and recycle of inorganic chemicals in the black liquor. To accomplish chemical recovery, black liquor is concentrated by evaporation and burned in recovery furnaces. Most of the organic and inorganic sulfur is reduced in the lower oxygen-poor region of the furnace to form an ash or smelt of molten chemicals, primarily sodium sulfide and carbonate. The upper zone of the recovery furnace, ideally an oxygen-rich zone, serves to oxidize the residual sulfur organics carried up from the reducing zone below.

Recovery furnaces also produce valuable process steam from the heat of the burning black liquor. Hot gases from the combustion zone relinquish most of their heat energy in passing over boiler tubes and heat economizers. Steam may be used elsewhere in the pulp-making process or sent to turbines for electrical power generation. Additional utilization of the furnace heat is accomplished by the use of a direct contact evaporator. Such an evaporator utilizes the heat of the flue gases to further evaporate black liquor just prior to its firing in the recovery furnace. Direct contact evaporation has one serious drawback, however, from an air-pollution standpoint--the stripping of hydrogen sulfide which occurs when acidic flue gases contact the black liquor. Following the direct contact evaporator, furnace gases pass through collectors (such as electrostatic precipitators and scrubbers) to remove particulate matter consisting of sodium salts and carbon particles. Exhaust gases containing the remaining particulates, plus the malodorous sulfur compounds, then pass to the atmosphere.

The sodium sulfide and sodium carbonate smelt, formed at furnace-grate level, falls into the smelt tank where it dissolves in water, forming the "green liquor." The sodium carbonate is converted to sodium hydroxide by the addition of lime. The reaction performed in the causticizer or shaker is shown below. (1) Calcium carbonate precipitates as a lime mud, and after washing is sent to the lime kiln where it is calcined to calcium oxide. (2) This fresh lime is then slaked (3) and available for further causticizing. After conversion of sodium carbonate to the hydroxide, the "green" liquor becomes "white" liquor and is ready for recycle as cooking liquor.

$$(1)\quad Ca(OH_2) + Na_2CO_3 \longrightarrow 2NaOH + CaCO_3$$

$$(2)\quad CaCO_3 \longrightarrow CaO + CO_2$$

$$(3)\quad CaO + H_2O \longrightarrow Ca(OH)_2$$

11.5.1.1 Emission Sources and Rates: The kraft pulp mill emits a wide range of air pollutants, with the malodorous sulfur gases being the most objectionable because of their low threshold of detection in the ambient air. Other categories of kraft mill emissions include particulates, mists, and less odorous gases which are emitted from numerous process points. Table 11-3 shows the atmospheric emission sources and the general category of atmospheric emission which each source contributes.[6] Table 11-4 identifies the emission category by chemical composition.[6]

TABLE 11-3

ATMOSPHERIC EMISSION SOURCES IN A KRAFT MILL[6]

Source	Emission Categories
Digester relief and blow gases	Malodorous gases and water vapor
Knotter and brown stock washers, washer seal tanks	Malodorous gases, mists and organic vapors
Black liquor storage	Malodorous gases
Black liquor oxidation tower	Malodorous gases and organic vapors
M. E. evaporators	Malodorous gases
Recovery furnace	Particulates, malodorous gases, other gases (including sulfur dioxide)
Smelt dissolver tank	Mists and odorous gases
Lime kiln	All categories
Causticizer	Mists
Bleach plant	Mists and other gases
Power boilers (including oil-fired and bark-fuel boilers)	Particulates and other gases
Paper incinerators	Particulates and other gases
Materials handling	Particulates

TABLE 11-4

ATMOSPHERIC EMISSIONS FROM KRAFT PULP MILLS[6]

General Category	Composition
Particulates	sodium carbonate, sodium sulfate (salt cake), calcium oxide (lime), sodium oxide, carbon (char), fly ash
Mists	sodium carbonate, sodium sulfate, black liquor, caustic and hypochlorite + sulfurous gases
Malodorous (sulfurous gases)	hydrogen sulfide, methyl mercaptan, dimethyl sulfide, dimethyl disulfide, ethyl mercaptan, isopropyl mercaptan, n-propyl mercaptan, ethyl sulfide, and others
Other gases (less odors and including organic vapors)	carbon monoxide, sulfur dioxide, chlorine and chlorine dioxide, carbon dioxide, methanol (wood alcohol), ethanol (rubbing alcohol), alpha-pinene, acetone
Water vapor	----

The largest source of potential particulate emission is the recovery furnace; other sources of particulate emission include the lime kilns, smelt tanks, and bark- and/or coal-fired power boilers. The recovery furnace can also account for half of the total potential sulfur emissions, although other sources such as the digesters and multi-effect evaporators should not be ignored as malodorous emission sources.

In the recovery furnace, heat is obtained from the combustion of the organic constituents of the black liquor, and the inorganic constituents are recovered as a molten smelt. The concentrated black liquor at 60 to 65% solids content is sprayed into the furnace where the water content is flashed off.

When the black liquor is burned in the furnace, an appreciable quantity of particulate is liberated. Chemical content of the solids entrained in the recovery furnace flue gases is a function of furnace operating conditions and feed liquor composition. Usually Na_2SO_4, Na_2CO_3, and

NaCl constitute 75 to 90% of the particulate weight. The remainder is composed of $NaHCO_3$, unburned organic material, and water-soluble fly ash. The relative mass fractions of Na_2SO_4, Na_2CO_3, and NaCl in the fume can vary greatly from mill to mill. For example, NaCl is present in measurable quantities when logs have been stored in salt water before chipping; inland mills have less NaCl passing through the recovery system.

The smelt recovered from combustion of black liquor in the recovery furnace is dissolved in water and weak wash in the dissolving tank. As a result of violent reaction and flashing, a considerable quantity of moisture containing dissolved sodium compounds is discharged from the dissolving tank to the atmosphere.

Boilers which are wholly or partially fired with bark are another source of particulate emissions. Fly ash is the dominant particulate emitted from this source.

Emission levels for the kraft pulping process are summarized in Table 11-1. Particulate emissions from kraft mills currently total about 239,000 tons/year.

11.5.1.2 Effluent Characteristics: The chemical and physical properties of effluents from kraft pulping processes are detailed in Table 11-2. Particulates emitted from the recovery furnace range from 50 to 85 wt. % less than 2 μ. Lime kiln particulates are 95 wt. % less than 25 μ, while those from the smelt tanks are 90 wt. % less than 5 μ.

11.5.1.3 Control Practices and Equipment: Electrostatic precipitators are normally used to recover particles emitted from the recovery furnaces. Electrostatic precipitators may remove 85 to 97% of the particulate matter while Venturi scrubbers may remove 60 to 95%.[7]

The recovery of particulate matter from the flue gases leaving the recovery furnace, lime kilns, and dissolving tanks is described in Reference 8. Uncontrolled emissions from the smelt tank may be as high as 20 lb/ton of pulp. Use of a simple water spray may reduce this to 5 lb/ton, while a mesh demister may further reduce this to 1 or 2 lb/ton.[7,9] The control equipment used to decrease smelt tank emissions are mesh pads, packed towers, orifice scrubbers, or cyclonic scrubbers. The pressure drop for an orifice scrubber is approximately 8 in. of water. The pressure drop across a mesh pad is usually less than 1 in. of water, but sprays located above the pads may be required periodically to remove collected chemicals.[11] The recovery of particulate matter from the flue gases leaving the recovery furnace (and from the lime kilns and dissolving tanks) is described in Reference 8.

To reduce fallout in the mill vicinity and/or comply with stack emission standards, some mills practice secondary wet scrubbing as an adjunct to the use of primary recovery devices on the recovery furnace flue gases. Six types of secondary scrubbers for particulate matter removal in flue gases are in use in the U. S. industry at the present time.[12/] These are usually low-pressure-drop devices of less than 2 in. of water. They may be constructed of fiberglass or lined with acid resistant brick or concrete. The wide variation in water usage rate for these secondary scrubbing installations is shown in Table 11-5.[12/] It has been reported that the initial installation cost of various secondary scrubbing systems ranges from $35,000 to $55,000/100 tons pulping capacity.[13/]

TABLE 11-5

WATER USAGE FOR SECONDARY SCRUBBING INSTALLATIONS[12/]

Type	gpm/1,000 cfm Water Use Rate	Shower Rate
Vertical impingement screen	0.4-2.3	1.0-2.3
Multiple Venturi impingement	4.6-11.3	10.8-22.6
Chevron baffle plate	0.3	8.7
Pease-Anthony cyclonic	0.5-4.1	1.2-7.6
Vertical baffle plate	0.6	1.2

The installation of scrubber units downstream of an electrostatic precipitator is discussed in Reference 14. Table 11-6 shows average performance data for this type of unit and Figure 11-4 gives the particle size efficiency curve. Tests showed conclusively that dust collection efficiency decreased when the flue gas entered the washer saturated with water vapor (at the dew point temperature). It is surmised that when flue gas enters the washer at a temperature considerably above the dew point, large quantities of steam or fog are produced at the first bank of spray nozzles, where the gas is cooled to the dew point. Solid particles carried in the gas act as condensation nuclei for the saturated steam, thereby resulting in the high collection efficiency for the 5 to 30 μ range particles as shown in Figure 11-4.

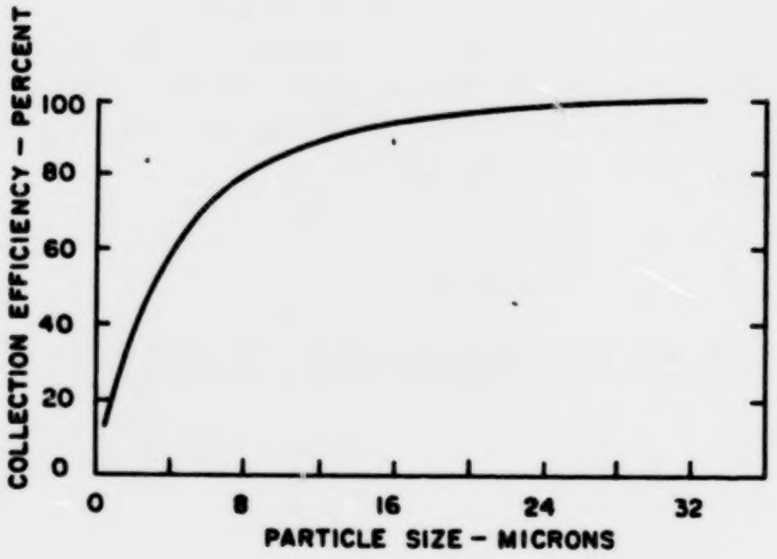

Figure 11-4 - Particle-Size Efficiency Curve TE Washer-Black Liquor Recovery Furnace*14/

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* Pressure drop less than 1 in. w.g.

TABLE 11-6

AVERAGE PERFORMANCE DATA FOR FULL-SCALE TE WASHER*[14]

Gas flow, ft^3/min	57,000
Dust loading, grains/std ft^3	
Inlet	0.21
Outlet	0.027
Efficiency, %	88
Soda ash recovered, lb/min	1.7
Liquid effluent from scrubber, gpm	25.3
Concentration, g/liter as $NaHCO_3$	7.73
Gas temperature, °F	
Inlet:	
dry-bulb	272
wet-bulb	169
Outlet:	
dry-bulb	166
wet-bulb	162

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* Pressure drop less than 1 in. w.g.

Venturi scrubbers are used on stack gases from recovery furnaces to serve as direct-contact evaporators by using black liquor as the scrubbing medium. The particulate collection efficiency of one such unit is reported to be 74.2%.[5] The pressure across this unit was not given. It was stated that steam-atomizing nozzles were installed in an effort to improve collection efficiency.

Wet scrubbers are also used on lime kiln stack gases. Test data for one unit are given in Table 11-7.[16]

Pilot plant studies have been conducted making use of electrostatic pre-agglomeration of black liquor boiler fume followed by a flooded disk or Venturi scrubber.[17]

Large diameter cyclones of 48 in. to 60 in. are commonly used for collection of the emissions from bark boilers. Recovery efficiencies are in the range of 98% with a pressure drop of 3 to 4 in. w.g.[10]

TABLE 11-7

TEST DATA, LIME KILN VENTURI SCRUBBER[16]

Inlet gas temperatures, °F	309-344
Exit gas temperatures, °F - sat'd	156-168
Scrubbing slurry temperatures, °F	155-166
Inlet gas volume, cfm at STP - 32°F, 29.9 in. Hg	17,400-24,700
Inlet gas volume cfm at duct conditions	27,800-40,000
Outlet gas volume, cfm at STP - 32°F, 29.9 in. Hg	20,400-25,800
Outlet gas volume, cfm at duct conditions	26,200-32,800

	Run No.					
	1	4	5	6	7	8
Pressure drop across venturi and cyclone, in w.g.	11.25	6.75	10.75	6.75	5.5	5.5
Scrubbing liquid used	Filtrate	Filtrate	Slurry	Slurry	Slurry	Slurry
Scrubbing liquid gpm	510	290	410	160	200	100
Scrubbing liquid, % solids	3.3	--	46.7	18	--	--
Inlet dust load, tons/day						
Acid insoluble	0.08	0.16	0.06	--	--	--
$CaCO_3$	4.14	14.70	19.62	--	--	--
Na_2SO_4	0.30	0.03	0.06	--	--	--
Na_2CO_3	2.34	2.41	1.64	--	--	--
Total	6.86	17.30	21.38			
Outlet dust load, tons/day						
Acid insoluble	0.01	0.05	0.02	0.01	0.09	0.03
$CaCO_3$	0.03	0.10	0.15	0.15	0.08	0.37
Na_2SO_4	0.04	0.01	0.02	0.02	0.02	0.01
Na_2CO_3	0.86	0.48	0.45	0.75	0.30	0.31
Total	0.94	0.64	0.64	0.93	0.49	0.72
Dust loading, grains/ft^3*						
Inlet	2.94	6.86	11.94	--	--	--
Outlet	0.45	0.24	0.30	0.40	0.18	0.27
Dust removal efficiency %						
For $CaCO_3$	99.3	99.4	99.5	--	--	--
For Na_2SO_4	86.5	63.3	59.6	--	--	--
For Na_2CO_3	63.0	80.0	72.5	--	--	--
Overall	86	96	97	--	--	--

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* Wet gas at STP 32°F, 29.9 in. Hg.

It has been reported that the large cyclones are preferred to the smaller diameter multicyclone systems. Part of the reason for this is the low density of the bark char which is easily re-entrained and does not flow well out of the collection hoppers.[10]

11.5.1.3.1 Control costs in kraft pulp mills: The cost of control equipment for the wood pulping industry is a major part of a NAPCA study conducted by Environmental Engineering, Inc., and the J. E. Sirrine Company.[11] Detailed cost studies for many different control systems and combinations were developed for this study. A portion of this cost information has been extracted from the above report and is included in the following section. The reader is directed to the original report for more detailed information and for a complete set of cost studies.

11.5.1.3.2 Descriptions of capital cost items:

Purchased equipment: Cost of the emission control device and all accessories and auxiliaries required for its full operation.

Equipment erection: The erection of purchased equipment only. The erection cost of building and foundations, piping and wiring is included elsewhere.

Equipment foundations and building: The installed cost of all equipment foundations, building and building foundations, floors, roof, stairs, and walkways, that are required for support, access, and enclosure of the control device.

Process and instrument piping: Cost of all pipe and pipe supports, erected, and including insulation and protective coating where required.

Power wiring and lighting: The installed cost of all power wiring and lighting is included. Wherever required, any substation, transformers, or switchgear costs are included under "Purchased Equipment."

Indirect capital cost: The summation of the above capital cost composes the total direct capital cost to which is added indirect cost as a percentage of direct cost. The following is a breakdown of this indirect cost:

15%	Contingency--Unforeseen conditions and items not practical to estimate
7%	Engineering--Preparation of specifications and working drawings, selection, and evaluation of equipment
1%	General Construction Overhead--Includes temporary facilities, contractual supervision, timekeeping, etc.
3%	Start-up Cost--Loss of production not included
2%	Spare Parts
2%	Sales Tax
30%	TOTAL

11.5.1.3.3 Description of annual cost items:

General: Any estimated annual cost may vary considerably from mill to mill. The following values may be considered typical and should provide reasonable comparisons of emission-control-device annual cost:

Direct operating cost: Direct operating cost consists of charges for:

(1) Operating labor, including overhead. A national average hourly rate of $4.25 has been assumed. To this rate, an additional 29% is added for vacations, sick pay, holidays, payroll taxes, insurance, and fringe benefits. (Total $5.50/hr)

(2) Power, electric, and/or steam. An electric cost of $0.01 per KWH, and a steam cost of $0.65/1,000 lb of steam has been used.

(3) Water. A water cost of $0.13/1,000 gal has been used.

(4) Maintenance, including maintenance labor, replacement parts, and maintenance materials.

Taxes and insurance: Local property taxes vary widely over the country. Generally, this is applied as a millage on the assessed valuation. Assuming the property is assessed at 50% and 30 mills tax is applied, then the property tax would be 1-1/2% of the construction cost.

1.5% of Capital Cost

An average insurance cost has been used for the entire pulp and paper mill.

0.5% of Capital Cost

Total Taxes and Insurance 2.0% of Capital Cost

Administrative costs: This is an average cost applied to the overall plant and includes all salaried personnel (officers and supervisors), fringe benefits for salaried personnel, legal and other professional services, public relations, contributions, and office supplies and expenses. This does not include any marketing costs.

5.0% of Capital Cost

Depreciation and interest (capital recovery): Depreciation plus interest charges were calculated from the following formula which is one of several commonly used for this purpose. An interest rate of 10% was assumed.

$$\text{Equal annual payment} = \frac{i(1 + i)^n \times 100\%}{(1 + i)^n - 1}$$

i = interest rate
n = life in years

SUMMARY OF CAPITAL CHARGE ITEMS
(As % of Capital Cost)

	Estimated Life of Equipment in Years		
Item	8	10	16
Taxes and Insurance	2%	2%	2%
Administration	5%	5%	5%
Depreciation and Interest (Capital Recovery)	18.7%	16.3%	12.8%
TOTAL	25.7%	23.3%	19.8%

Net annual costs have been computed on basis of equipment life as follows:

Electrostatic Precipitators - 10 years
Venturi Scrubbers - 8 years
Packed Towers - 10 years
Cyclones - 16 years

UTILITY COST

Item	Fixed Charges	Operating Costs Fuel, Labor, Maint., Etc.	Total (Rounded to Nearest Cent)
Steam $/1,000 lb. Based on 1,000 BTU/lb	$0.116	$0.535	$0.65
Electricity $/KWH	0.0023	0.0077	0.01
Water $/1,000 gal.	0.104	0.046	0.15
Kraft Waste Treatment $/1,000 gal. (primary and secondary treatment)	0.13	0.03	0.16

These are values that may be considered typical in a general sense. All of these values vary considerably from mill to mill--any proper evaluation of control cost should be specifically calculated for the individual mill. However, the above costs should provide reasonable comparisons of emission-control method for this study.

CHEMICAL COSTS
Per Ton Except as Noted

Salt Cake	$34.00 East 24.50 West	Average: $30.00
Lime (CaO)	15.00	Average: 15.00
Sulfur	39.00 to 42.00/long ton	Average: 40.00
Soda Ash	31.00 to 32.00	Average: 31.00
Caustic Soda	57.00/ton of NaOH in a 50% solution	
Magnesium Hydroxide	37.68/ton 100% solids--tank car lots, FOB, Michigan	
Chlorine (Papermakers)	3.35/100 lb.	

Case descriptions: The following cases have been considered for application of control methods to recovery systems. (See Reference 11 for complete study.)

Case 1. Replacement of an existing 90% AOE* precipitator with a higher efficiency precipitator.

Case 2. Installation of additional control equipment in series with an existing 90% AOE precipitator.

Case 3. Installation of a cyclonic scrubber in series with an existing 95% precipitator located on the roof.

Case 4. Application of additional control methods to an existing recovery system with an 80% AOE black liquor Venturi.

Case 5. Installation of a black-liquor oxidation system to an existing recovery system.

Case 6. Capital costs of new recovery systems.

11.5.1.3.4 Recovery furnace system:

Application: This case is based on the replacement of an existing 90% AOE precipitator with a higher efficiency precipitator. Most of the existing older recovery precipitator installations are arranged with the precipitator on the ground. Usually there is no additional space on the ground in the vicinity of the recovery unit; therefore, an additional precipitator would have to be installed above the existing precipitator. Further, the existing precipitator could not be removed and replaced with a new one since this would require a lengthy mill shutdown resulting in a high dollar cost due to the loss of production.

Costs: The capital costs are based on a double chamber, common wall, tile construction precipitator. Auxiliaries included are: agitators, dampers, circulation pumps, instruments and controls for proper operation of the above, and revised ductwork to connect the addition of replacement precipitator in the system. The cost also reflects the structure required to support this addition, and the demolition cost for removal of the existing precipitator. Capital costs and net annual costs are presented in Figures 11-5 through 11-7.

Effectiveness: Particulate removal. Methods are considered for replacing a 90% AOE precipitator on an existing recovery boiler. These methods and their particulate efficiencies are as follows:

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* Average operating efficiency.

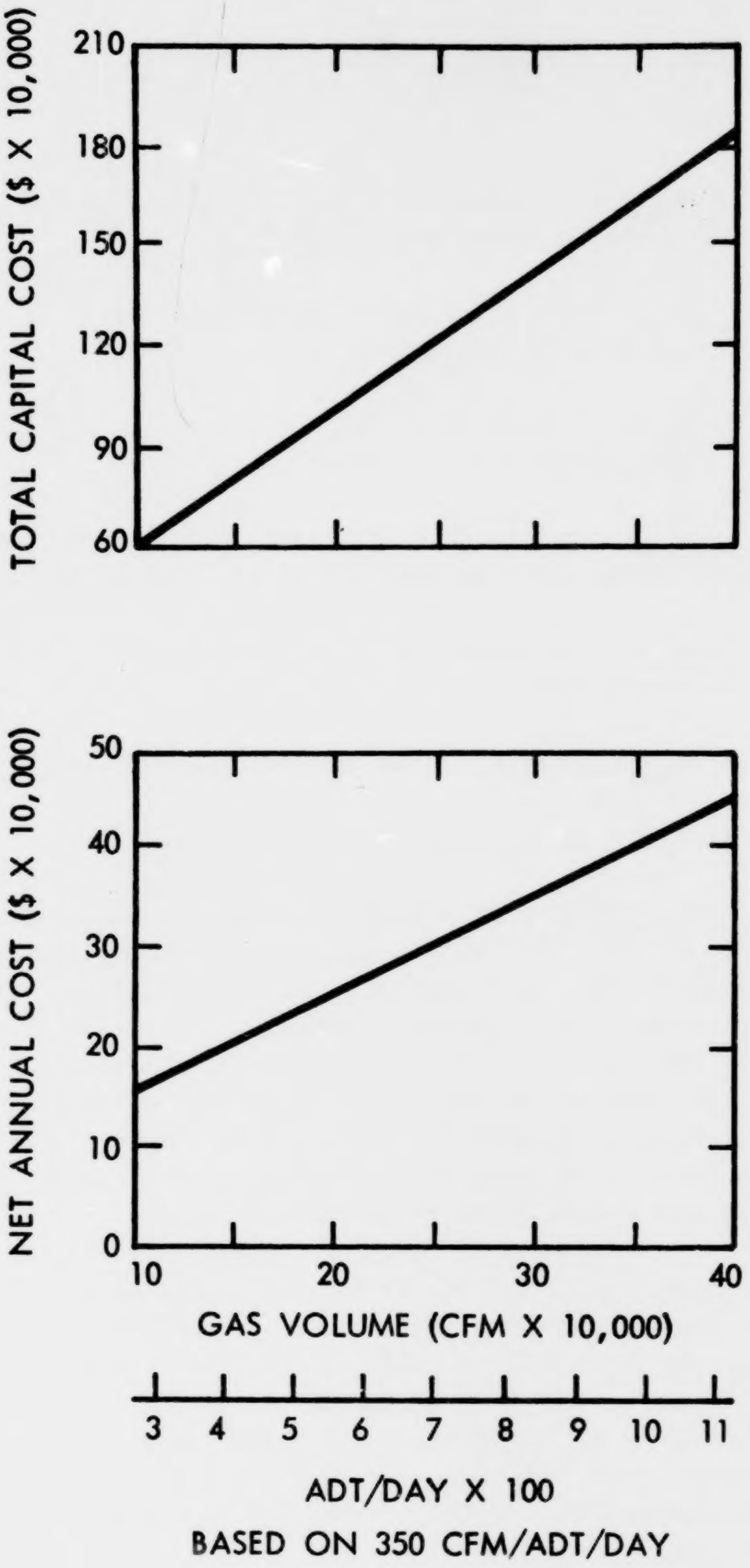

Figure 11-5 - Control Method Costs for 99.9% Efficiency Electrostatic Precipitator Replacing an Existing Precipitator - Recovery Boiler (99.5% A.O.E.)

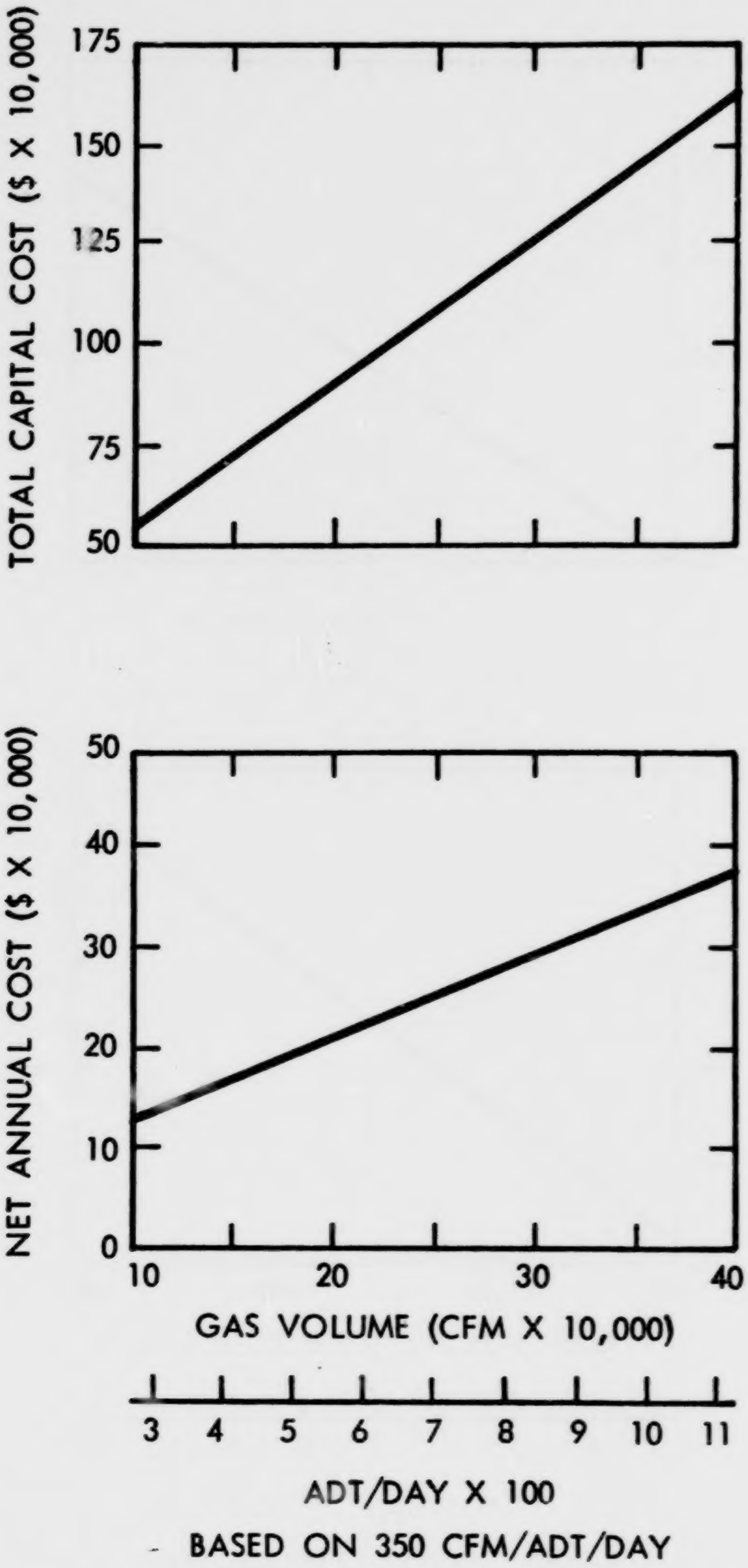

Figure 11-6 - Control Method Costs for 99.5% Efficiency Electrostatic Precipitator Replacing an Existing Precipitator - Recovery Boiler (99.0% A.O.E.)

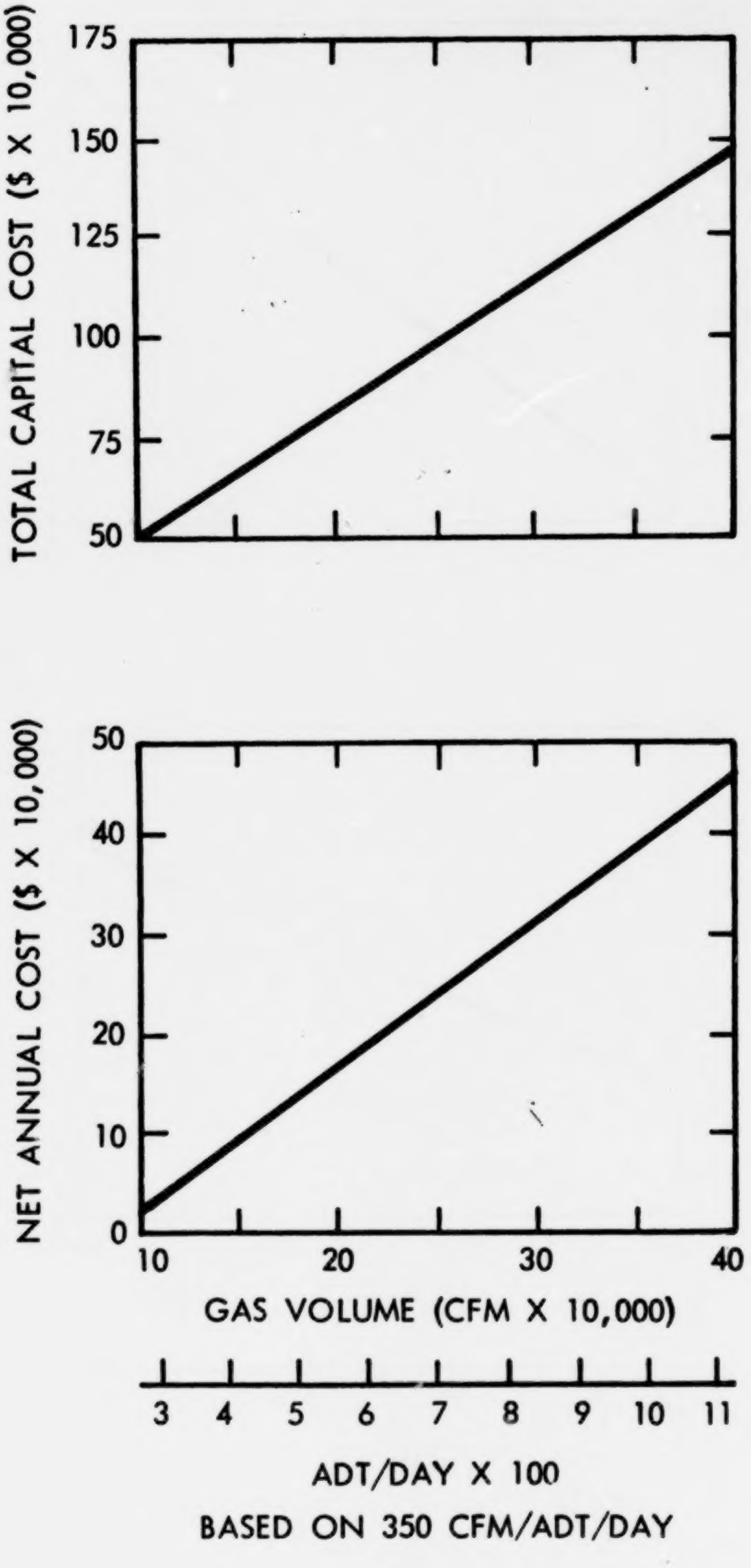

Figure 11-7 - Control Method Costs for 99.0% Efficiency Electrostatic Precipitator Replacing an Existing Precipitator - Recovery Boiler (98.5% A.O.E.)

Control Method	Guaranteed Efficiency	Annual Operating Efficiency
Precipitator	99.9	99.5
Precipitator	99.5	99.0
Precipitator	99.0	98.5

11.5.1.3.5 Smelt-dissolving tanks:

Application: The molten inorganic chemicals leave the furnace through smelt spouts to an agitated dissolving tank which contains weak wash liquor obtained from washing lime sludge in the succeeding causticizing operation. After being cooled and dissolved in the weak wash, the smelt solution is referred to as green liquor. Shatter nozzles are used to inject steam and/or recirculated green liquor into the solid smelt stream from the furnace to disperse the molten chemicals and ensure its safe dissolution.

Large quantities of water vapor are released by the green liquor which cools the molten smelt and by the steam from the shatter jets. Particles of smelt and droplets of green liquor become entrained in these vapors and are exhausted through the smelt-dissolving-tank vent.

The gas vented from the smelt-dissolving tank has a temperature of approximately 200°F and contains traces of organic sulfur compounds and particulate matter with a concentration of 1 to 1.5 grains/SCFD. The particulate matter is mostly sodium sulfide and sodium carbonate.

The majority of mills provide control equipment to minimize the emission of these chemicals and droplets to the atmosphere. Control equipment which is currently in use is as follows:

(1) Mesh pads. Mesh pads are used extensively to collect chemicals in dissolving-tank vents. Sprays located above the mesh pads operate periodically to remove the collected chemicals which are returned to the smelt-dissolving tank. A fan is not normally required due to the low pressure drop.

(2) Packed towers. Packed towers have been reported at two mills where they operate successfully. One concern with packed towers is the possibility of plugging; however, periodic use of condensate as scrubbing liquid is reported to remove any solids buildup.

(3) Orifice scrubber. This scrubber has been installed at several mills and is reported to be successful where the scrubber is adequately sized. Due to the pressure drop (approximately 8 in. H_2O) of this scrubber, inadequate sizing or improper operation may have a significant effect on emissions (for example, higher than design flows may require bypassing the scrubber).

Costs:

Cyclonic scrubber. This control method is based on the installation of a single cyclonic scrubber on an elevated floor within the confines of an existing recovery boiler building and adjacent to the existing vent stack. Since the capital cost and operating cost of the cyclonic scrubber is very similar to a packed tower, costs have not been calculated for the cyclonic scrubber. The reader is referred to the costs on the packed tower.

Packed tower. This control method is based on the installation of a single packed tower on an elevated floor within the confines of an existing recovery boiler building and adjacent to the existing vent stack. In addition, the following auxiliaries are included: an axial flow fan and motor located in the outlet of the tower, a circulation pump and motor, instruments and controls for proper operation of the above, piping for make-up circulation and tower effluent to dissolving tank, and revised ductwork including a by-pass to connect the tower to the existing vent stack (Figure 11-8).

Orifice scrubber. This control method is based on the installation of a single low-energy scrubber on an elevated floor within the confines of an existing recovery boiler building and adjacent to the existing vent stack. In addition, the following auxiliaries are included: an axial flow fan and motor located in the outlet of the tower, a circulation pump and motor, instruments and controls for proper operation of the above, piping for make-up circulation and scrubber effluent to dissolving tank, and revised ductwork including a by-pass to connect the scrubber to the existing vent stack (Figure 11-9).

Mesh pad. This control method is based on the installation of a mesh pad assembly in an existing recovery boiler vent stack.

Allowances have been included for the following: alterations to existing vent stack, normal piping for spray wash, and instruments and controls for proper operation. Cost curves are presented in Figure 11-10.

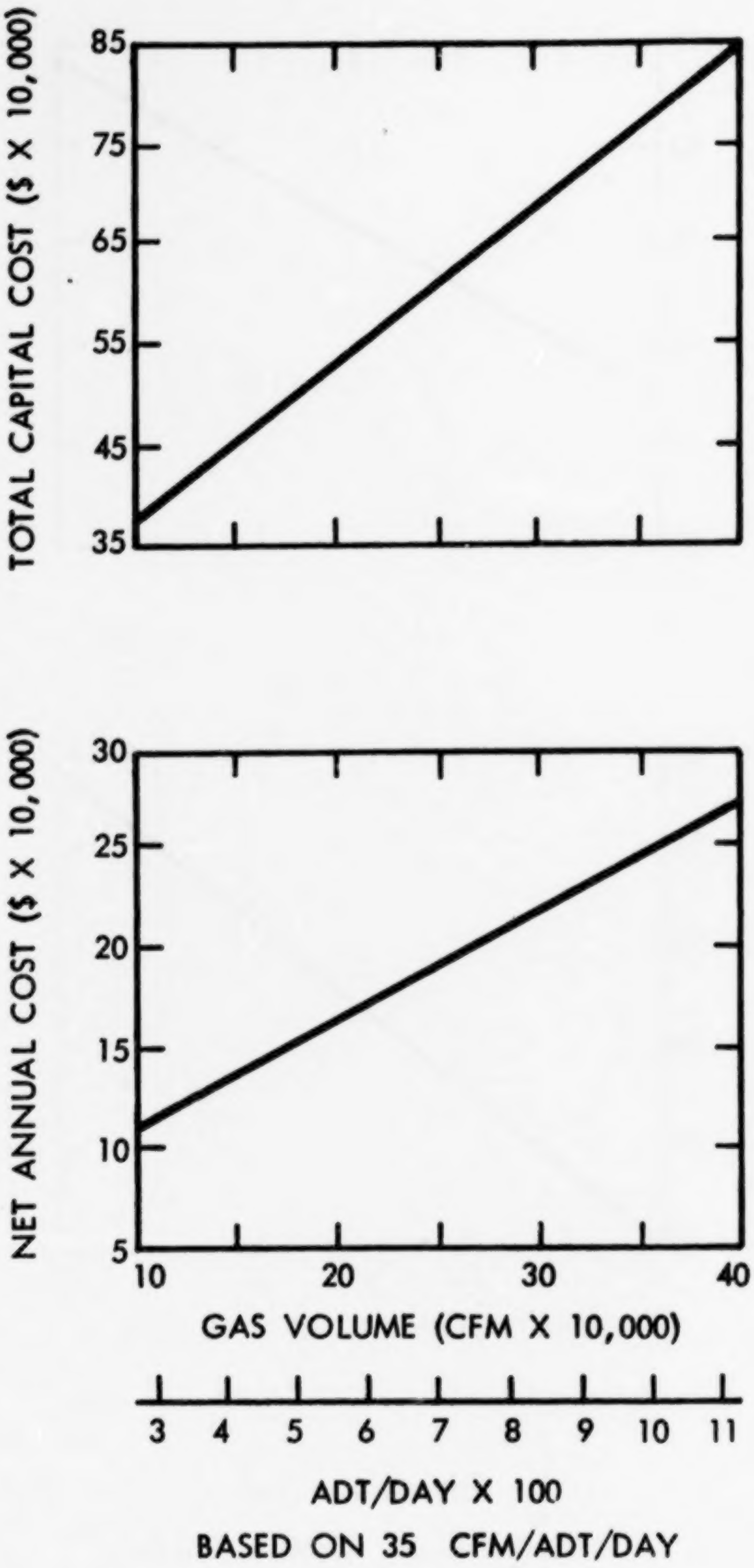

Figure 11-8 - Control Method Costs for Packed Tower Added to Smelt-Dissolving Tank Vent

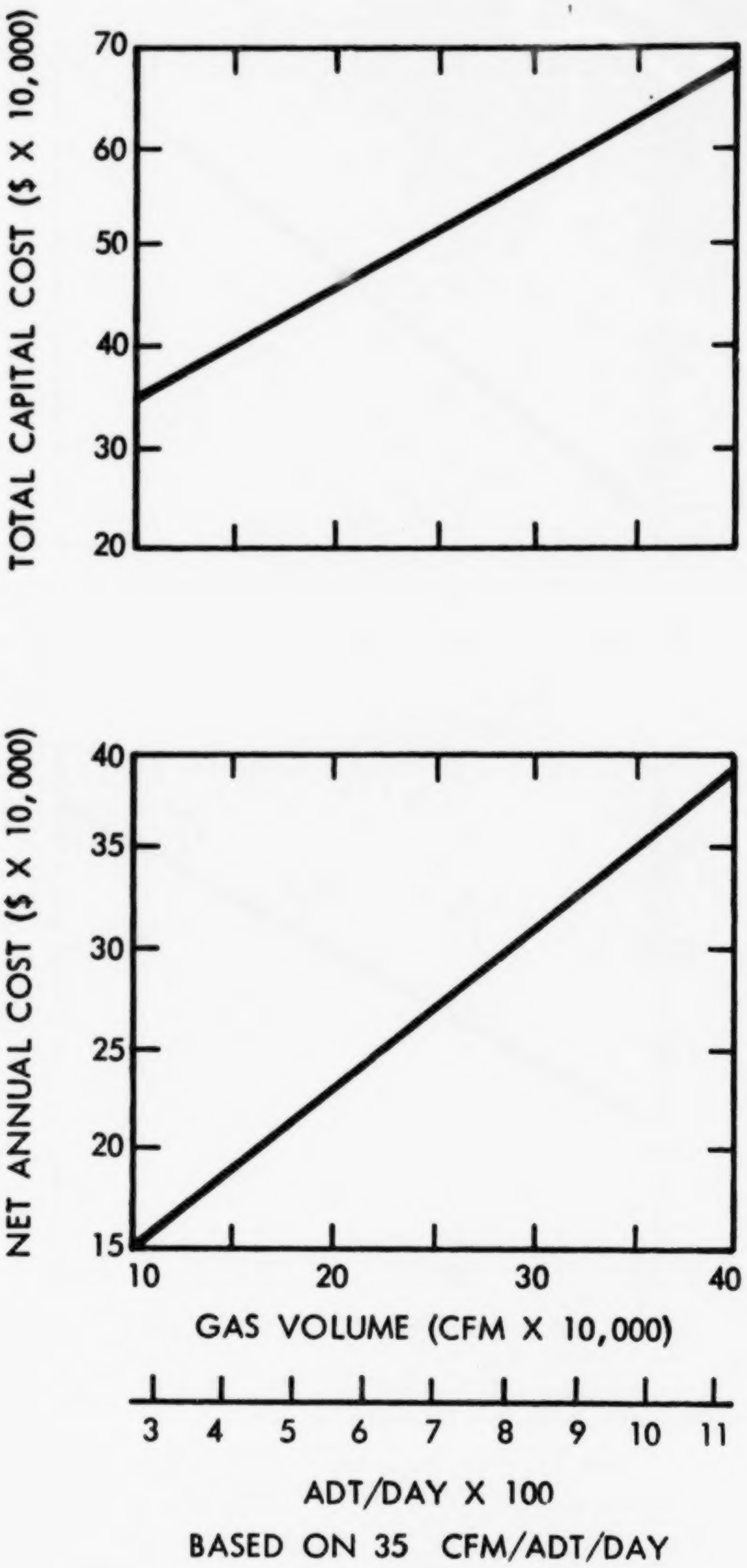

Figure 11-9 - Control Method Costs for Orifice Scrubber Added to Smelt-Dissolving Tank Vent

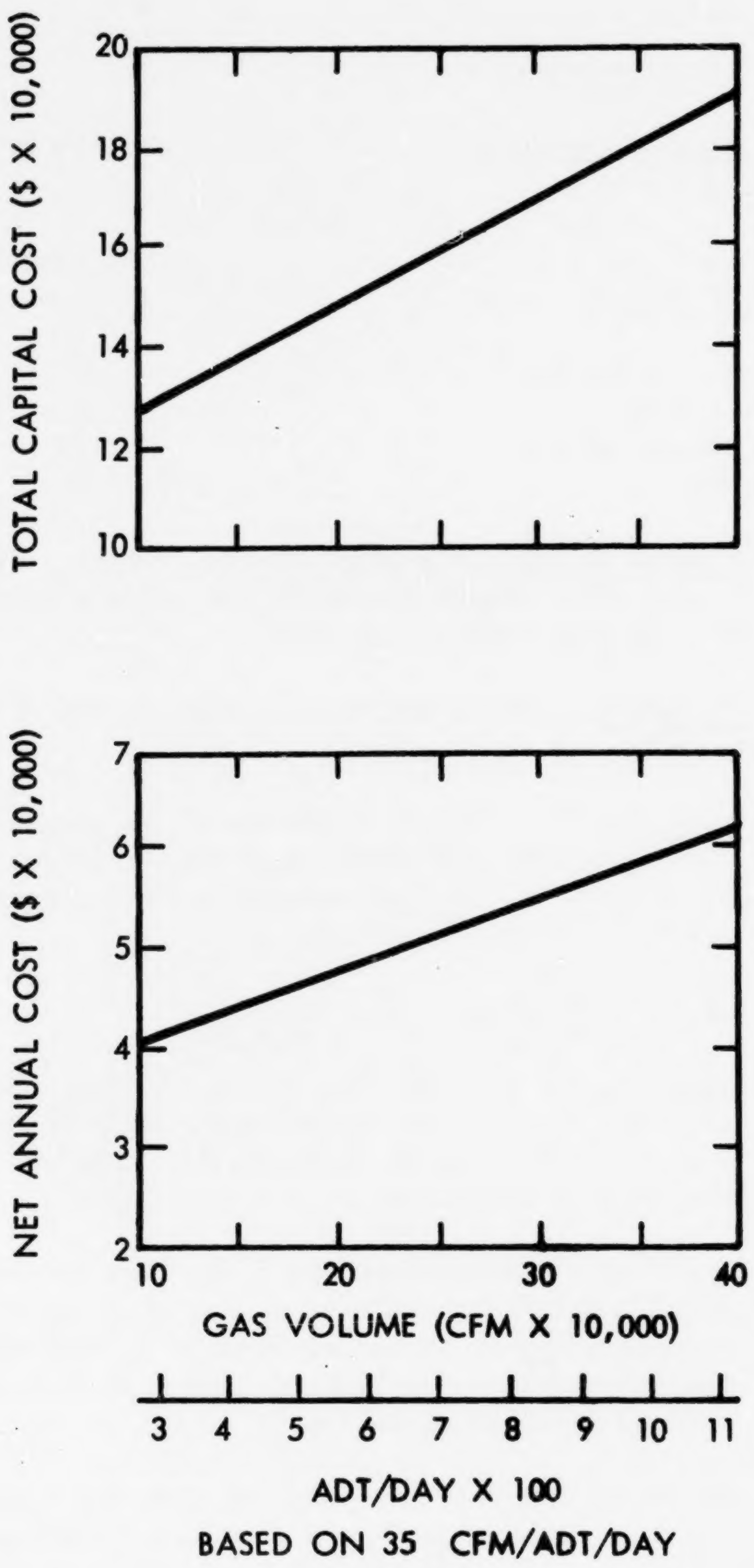

Figure 11-10 - Control Method Costs of Mesh Pad Added to Smelt-Dissolving Tank Vent

Effectiveness:

Particulate removal. Efficiencies for the methods considered are as follows:

Control Method	Annual Operating Efficiency
Cyclonic Scrubber	80
Packed Tower	90
Orifice Scrubber	97
Mesh Pad	75

Reduced sulfur and sulfur dioxide removal. Depending on the scrubbing liquid used, both the packed tower and orifice scrubber would have potential for removing sulfur compounds.

Operation. Of the methods considered, the orifice scrubber should be the least subject to plugging.

Summary. The orifice scrubber and the packed tower are the most effective control methods for either particulate or gaseous pollutant removal. The orifice scrubber is less susceptible to pluggage and has the highest particulate collection efficiency.

11.5.1.3.6 Lime kiln:

Application: This control method is based upon the addition of a high-energy Venturi scrubber to replace existing 80% AOE cyclonic-type dust collectors. The system is to be arranged such that change over to a new system may be made with a minimum of lost production.

As a matter of convenience and water conservation, most kraft mills use contaminated condensate as a scrubbing liquid in the kiln scrubber. The condensate system is backed up with a fresh water supply. During time of chemical unbalance or lack of supply of condensate, fresh water is substituted as a scrubbing medium.

Any mercaptans which are emitted from the kiln stack come from the contaminated condensate used as a scrubbing liquid and make-up wash water in this system. Substitution of fresh water in these systems would eliminate emission of mercaptans from the kiln stack.

This substitution of fresh water as a scrubbing medium appears simple and relatively inexpensive. However, it must be emphasized that the lime kiln and causticizing areas are the prime users of contaminated condensate generated in other areas of the mill. If fresh water is used in place of contaminated condensate, the load to the waste-treatment system will be increased by the amount of water substituted.

The emissions from incineration of noncondensible sulfur-bearing compounds in the lime kiln are not being considered in this particular control method.

Costs: The capital costs are based upon purchase of equipment and installation of the new scrubbing system while the existing system is in operation. Items included are as follows:

(1) New induced draft fan with drive
(2) New scrubber, mist eliminator and stack
(3) New pumps with drives
(4) Modification to existing hot gas ductwork

Also included in the costs are new foundations and structures required to support the equipment and demolition cost for removal of the existing scrubbing system, once the new system is placed in operation. Cost curves are presented in Figures 11-11 and 11-12.

Effectiveness: This study considers a single method of replacing a low efficiency cyclonic-type dust collector with a high-energy Venturi scrubber. The new method is to have a 99.0 or 99.9% lime solids collection efficiency. AOE and design efficiencies are considered to be the same.

(1) The new system will replace an existing and operating inefficient system.

(2) The efficiency of solids collection of high-energy scrubber is a direct factor of the pressure drop taken across the throat of the scrubber. Because of this item the capital cost between a 99.0% and 99.9% efficiency would be very similar. Equipment sizing would be essentially duplicate in either case and the only variable would be a higher horsepower motor for driving the induced draft fan. Variables in operating cost are shown on the cost curves.

(3) High-efficiency scrubbers are important to the pulping industry for recovery of soda. Volatile soda compounds in the kiln exhaust gases are more difficult to recover than solids but are also more valuable. Equipment manufacturers presently estimate that a scrubber with 99.9% lime

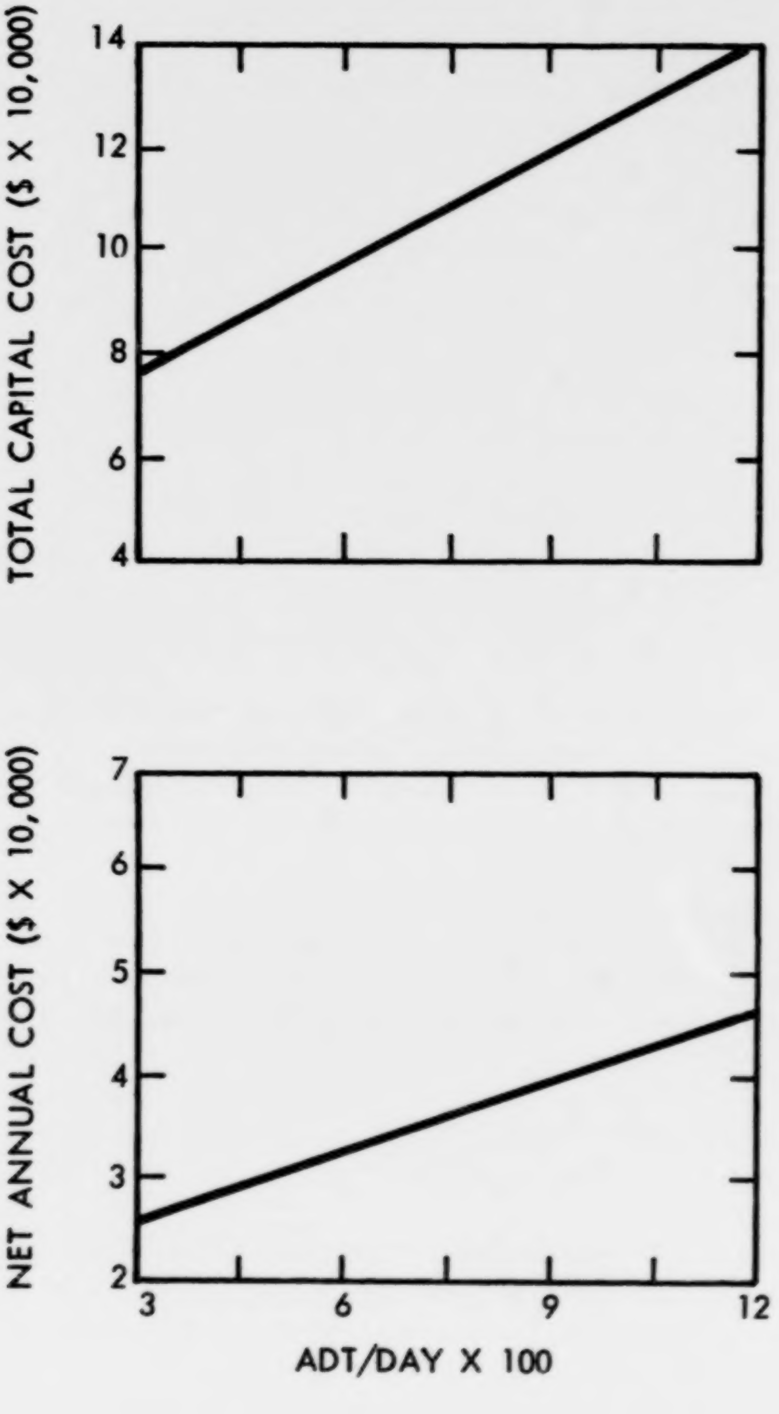

Figure 11-11 - Control Method Costs for Fresh Water Venturi Added to Lime Kiln - 99.0% Lime Solids Collection

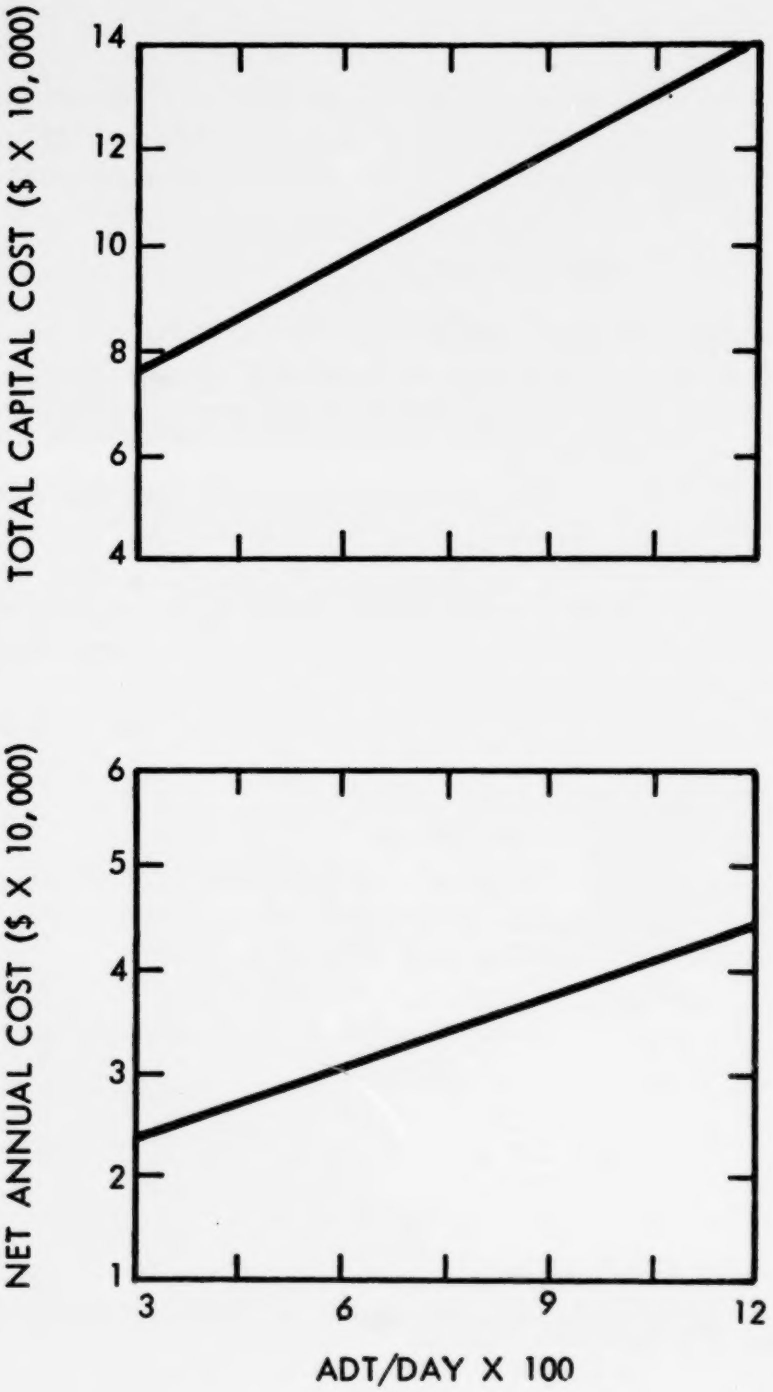

Figure 11-12 - Control Method Costs for Fresh Water Venturi Added to Lime Kiln - 99.9% Lime Solids Collection

solids collection efficiency will recover 90 to 95+% of the soda fume in the kiln exhaust gases. Ninety-nine percent lime solids collection should be equivalent to approximately 70% collection of soda fume.

11.5.1.3.7 Power boilers:

Application: This case is based on the addition of an electrostatic precipitator following an existing dust collector for a coal-fired power boiler. Two precipitator sizes are considered.

Costs: Curves for capital costs and net annual operating costs are presented in Figures 11-13 and 11-14.

The equipment costs are based on a double chamber, steel shell precipitator. All labor and material for a complete installation are included in the capital cost and the net annual operating cost. The precipitator size is based on firing coal containing 2% sulfur.

Effectiveness:

Particulate removal. Guaranteed particulate efficiencies for the two precipitators considered are 99.0% and 90.0%. The resulting total annual operating efficiencies are:

Precipitator Guaranteed Efficiency	Precipitator AOE	Dust Collector AOE	Total AOE
99.0%	98.0%	80.0%	99.0%
90.0%	89.0%	80.0%	98.0%

Reduced sulfur and sulfur dioxide removal. Precipitators are ineffective for removing sulfur compounds.

Operation. The operating characteristics of the precipitators should be identical.

11.5.2 Sulfite Process

Little attention has been paid to the air pollution aspects of sulfite pulping. The pollution problem is not nearly as severe as in the kraft process. Some terpene-like odors, SO_2 leaks, and particulates from recovery furnace and steam power plants are the principal effluents.

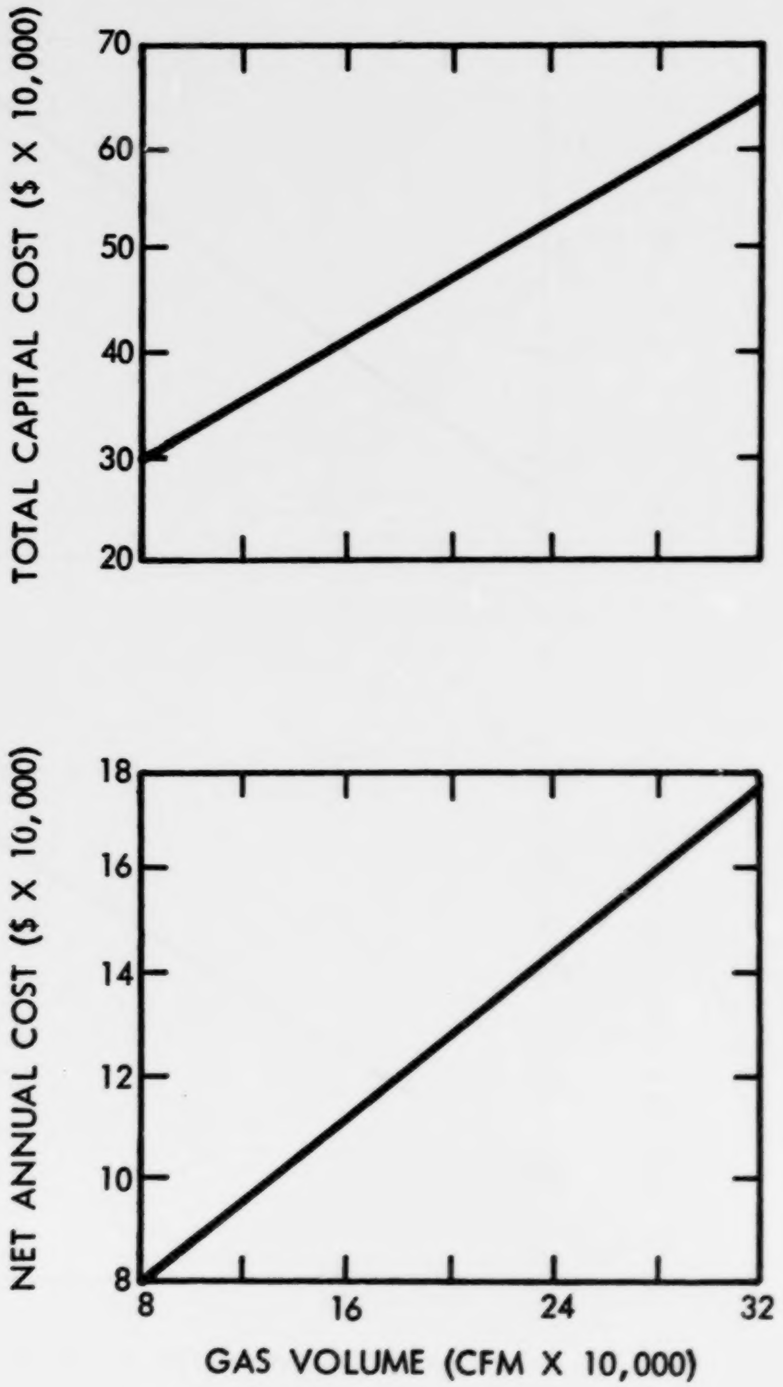

Figure 11-13 - Control Method Costs for 99.0% Efficiency Electrostatic Precipitator Added to an Existing 90% Efficiency Dust Collector Coal-Fired Power Boiler (99.0% AOE)

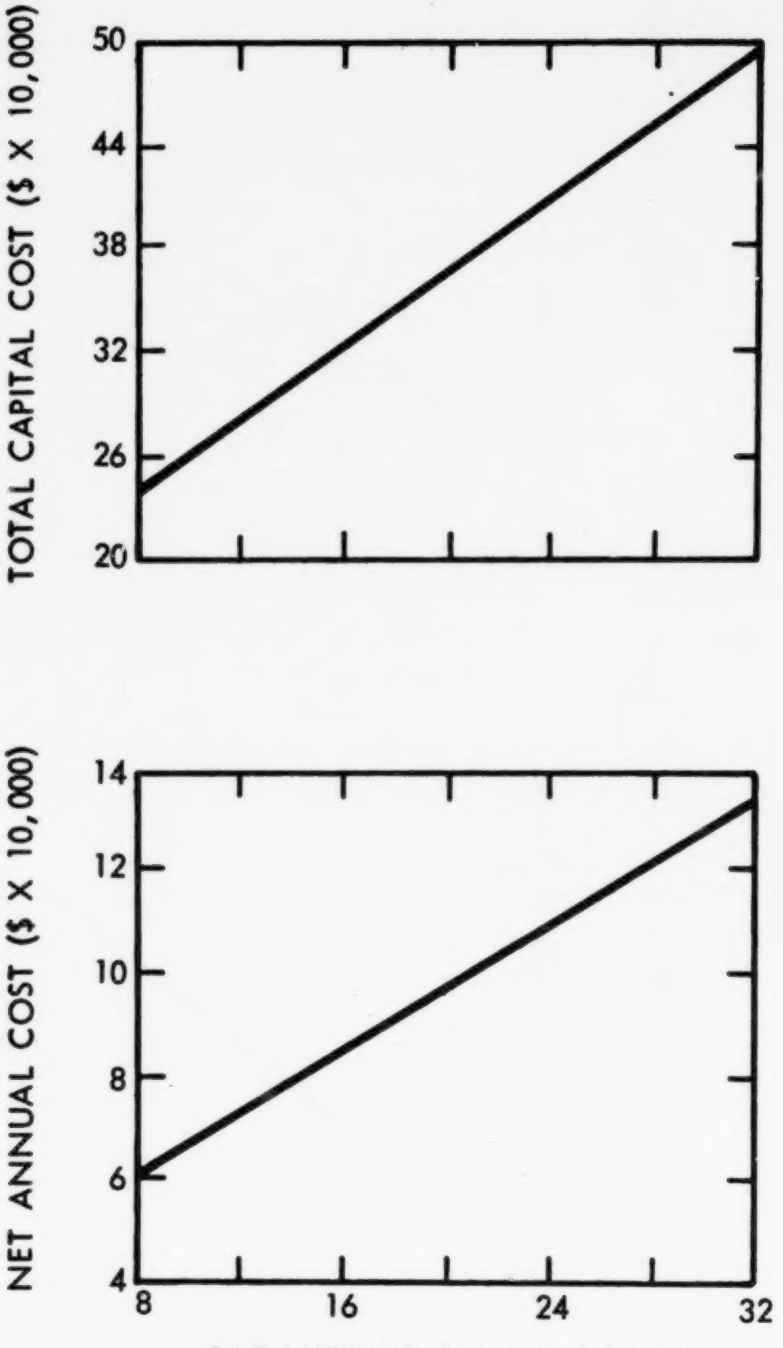

Figure 11-14 - Control Method Costs for 90.0% Efficiency Electrostatic Precipitator Added to an Existing 90% Efficiency Dust Collector Coal-Fired Power Boiler (98.0% AOE)

Little consideration is currently being given to calcium or sodium as a future base in U. S. sulfite mills. Burning of calcium spent sulfite liquor yields combustion products in a form precluding reuse of the base chemical or sulfur value. Incineration of sodium liquor produces a mixture of sodium compounds requiring processing in satellite operations to reconstitute the base chemical for pulping. Ammonia and magnesium liquor can be burned in a relatively simple system yielding the sulfur combustion product in the form of sulfur dioxide for recovery. Only the magnesia-base affords direct recovery of the base chemical.

Figure 11-15 illustrates a flow diagram for an ammonia-base pulping and recovery plant while Figure 11-16 presents the essential aspects of the magnesia-base liquor recovery process.

Meager data on emissions from sulfite mills exist in the literature. Table 11-8 summarizes some data from a pilot unit for ammonia-base liquor burning. Other emission data for sulfite mills are presented in Tables 11-1 and 11-2.

TABLE 11-8

AMMONIA-BASE LIQUOR BURNING
(Pilot Unit)

Dust loading: 1 - 2 lb/1,000 lb. of gas

Particle density: 1.5 - 2.0 g/cm^3

Particle size (average): 100 μ

Furnace exit gas temperature: 1,750 - 2,240°F

SO_2 at stack volume: 10 - 350 ppm

11.5.3 Semi-Chemical Pulping

Emissions from semi-chemical pulping plants are less intense than those from conventional pulping processes because of milder conditions. Emissions vary depending on process employed; e.g., neutral sulfite, or kraft. In the latter case, the air pollution problems will parallel those described under kraft pulping, but will be of a lower order of magnitude.

Very little data on emissions from semi-chemical pulping have been reported. Available information is summarized in Tables 11-1 and 11-2.

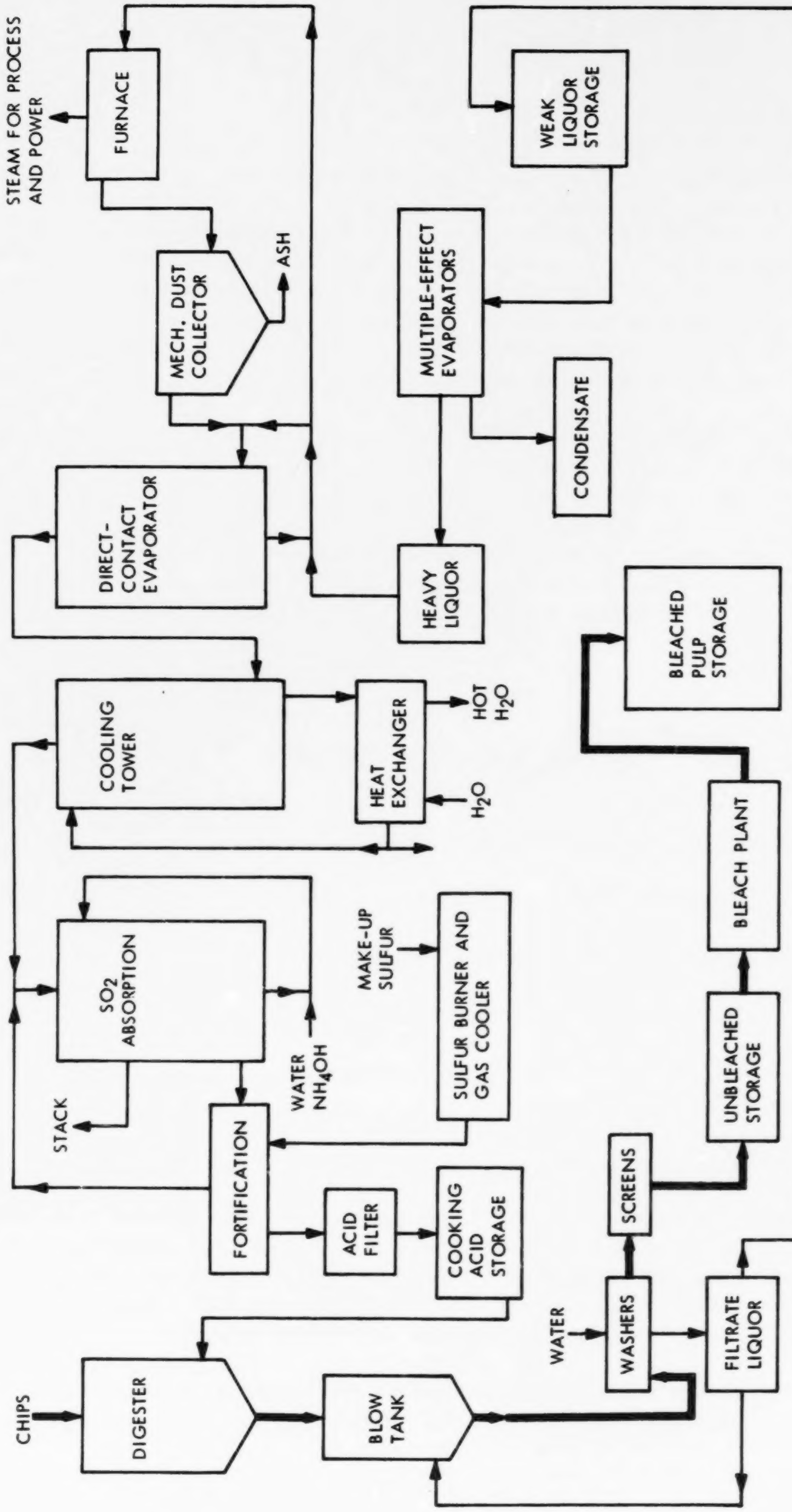

Figure 11-15 - Sulfite Pulping Process, Ammonia-Base Recovery

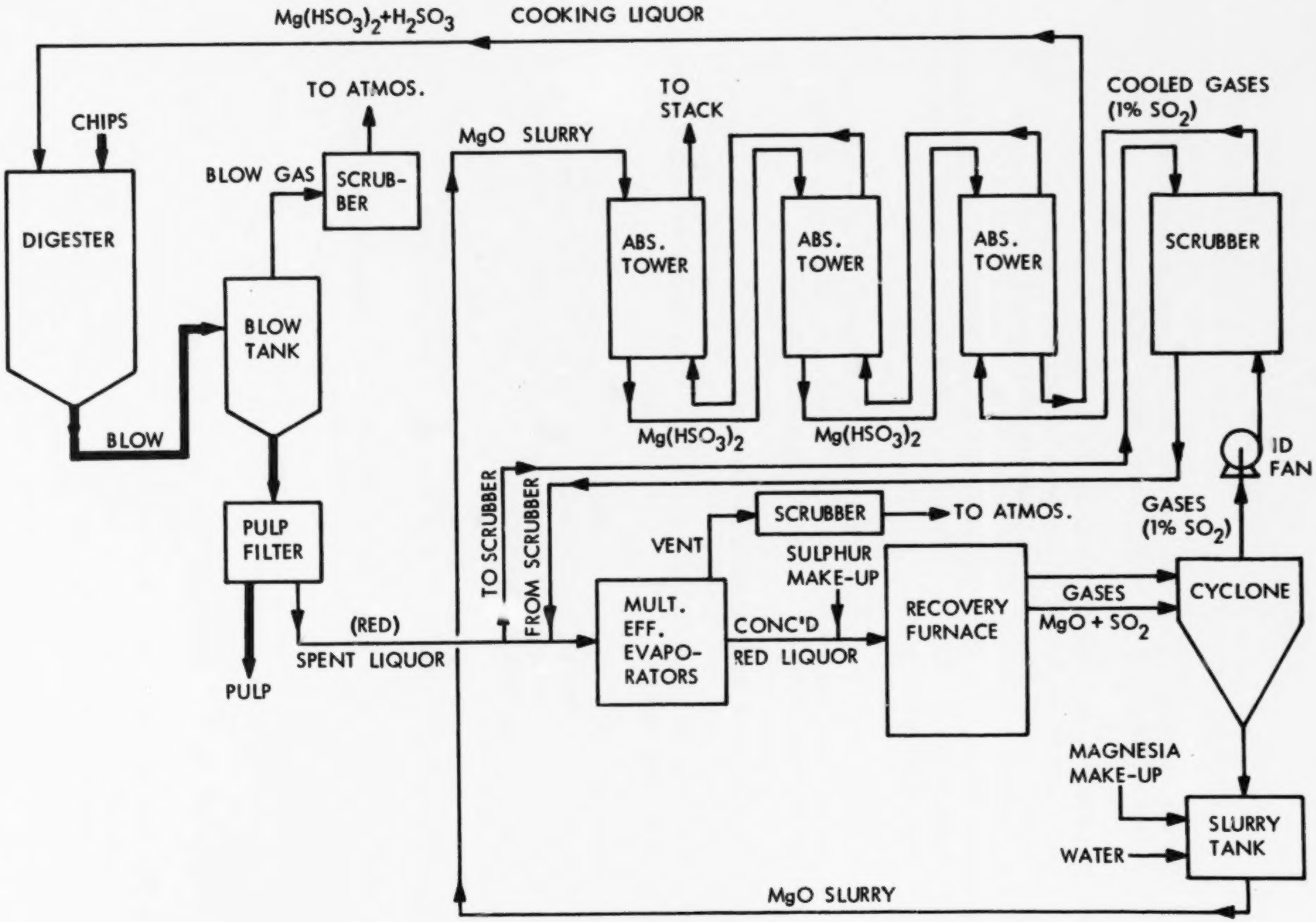

Figure 11-16 - Sulfite Pulping Process, Magnesia-Base Recovery

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CHAPTER 12

LIME MANUFACTURE

12.1 INTRODUCTION

Lime is one of the most widely used chemicals. It is used for medicinal purposes, insecticides, plant and animal food, gas absorption, precipitation, dehydration, and causticizing. It is also employed as a reagent in the sulfite process for papermaking, manufacturing of high-grade steel and cement, manufacturing of soap, rubber, varnish, refractories, and sand-lime brick.1/

The major air contaminant from lime manufacture is dust: limestone dust from handling, crushing, and screening operations; quicklime dust from kiln discharge, handling, shipping, and milling operations; hydrate lime dust from hydrator operations, milling, and packing.2/

The manufacturing process, particulate emission sources, particulate emission rates, effluent characteristics, and control practices and equipment are discussed in the following sections.

12.2 LIME MANUFACTURING PROCESS

A simplified flowsheet for lime manufacture is presented in Figure 12-1. Following crushing and screening, the limestone is fed to kilns for calcination or burning. Lime burning is conducted in vertical, rotary, grate, fluosolid, and calcimatic kilns. Rotary kilns are used by a majority of plants.

Although the major tonnage of lime is sold as quicklime, there is still a substantial production of hydrated lime. (This hydrated lime does not include production by the many consumers of quicklime who slake their own lime into a putty, slurry, or milk-of-lime preparatory to their use.) This product is made by the lime manufacturer in the form of a fluffy, micron-sized, dry, white powder, and its use obviates the necessity of slaking by the consumer. A flow diagram of a commercial dry hydration plant is shown in Figure 12-2.

This process consists of adding water slowly to a crushed or ground quicklime in a premixing chamber or a vessel known as a hydrator which mixes and agitates the lime and water. The amount of water to be added is critical. If too much water is added, it will be impossible (or require costly drying) to produce the desired dry form; if too little is added, incomplete hydration will cause degraded quality, namely, chemical instability and structural unsoundness.

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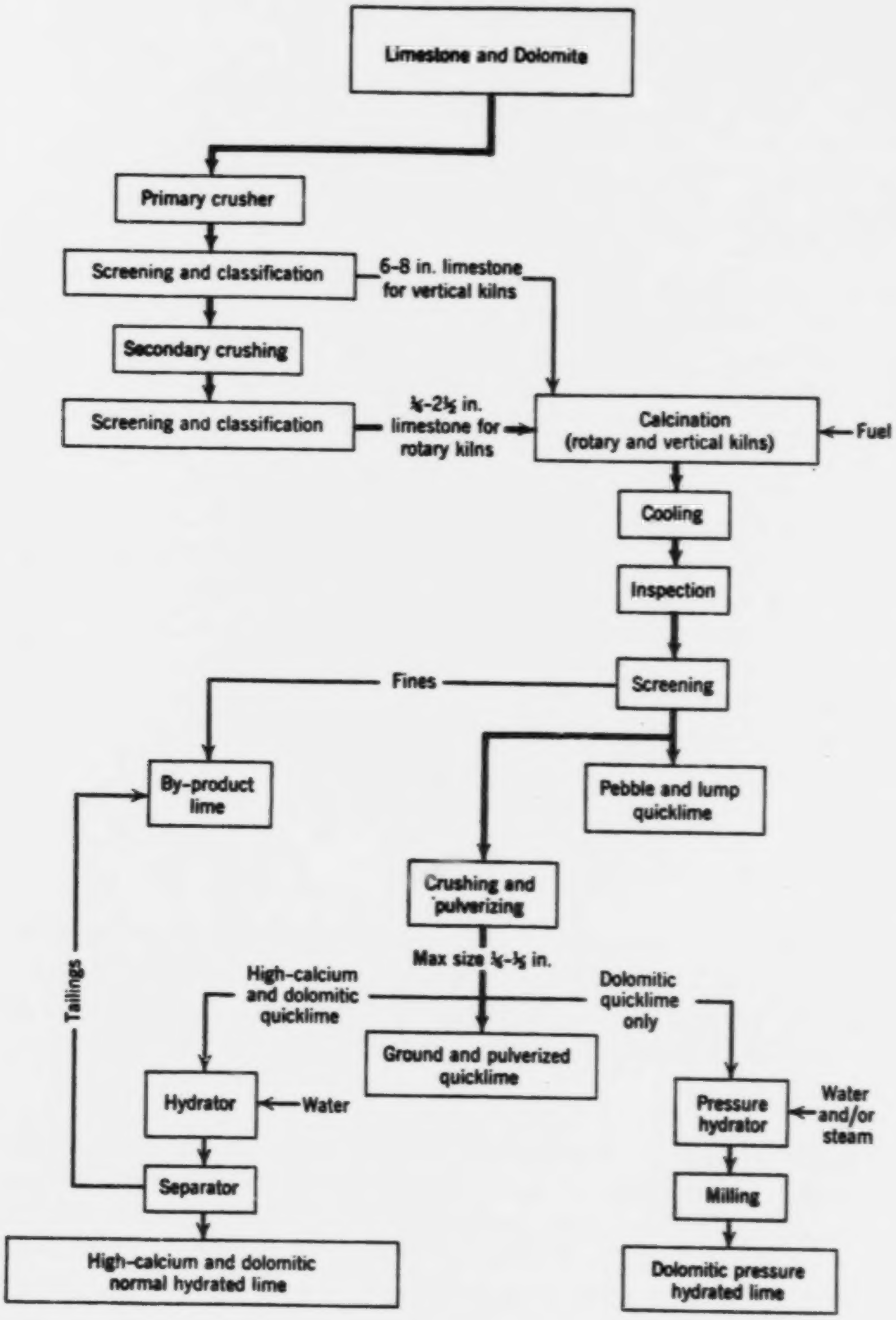
Limestone and Dolomite
Primary crusher
Screening and classification
6-8 in. limestone for vertical kilns
Secondary crushing
Screening and classification
¼-2½ in. limestone for rotary kilns
Calcination (rotary and vertical kilns)
Fuel
Cooling
Inspection
Screening
Fines
By-product lime
Pebble and lump quicklime
Crushing and pulverizing
Max size ⅛-¼ in.
Tailings
High-calcium and dolomitic quicklime
Dolomitic quicklime only
Ground and pulverized quicklime
Hydrator
Water
Pressure hydrator
Water and/or steam
Separator
Milling
High-calcium and dolomitic normal hydrated lime
Dolomitic pressure hydrated lime

Figure 12-1 - Simplified Flowsheet for Lime and Limestone Products[2]

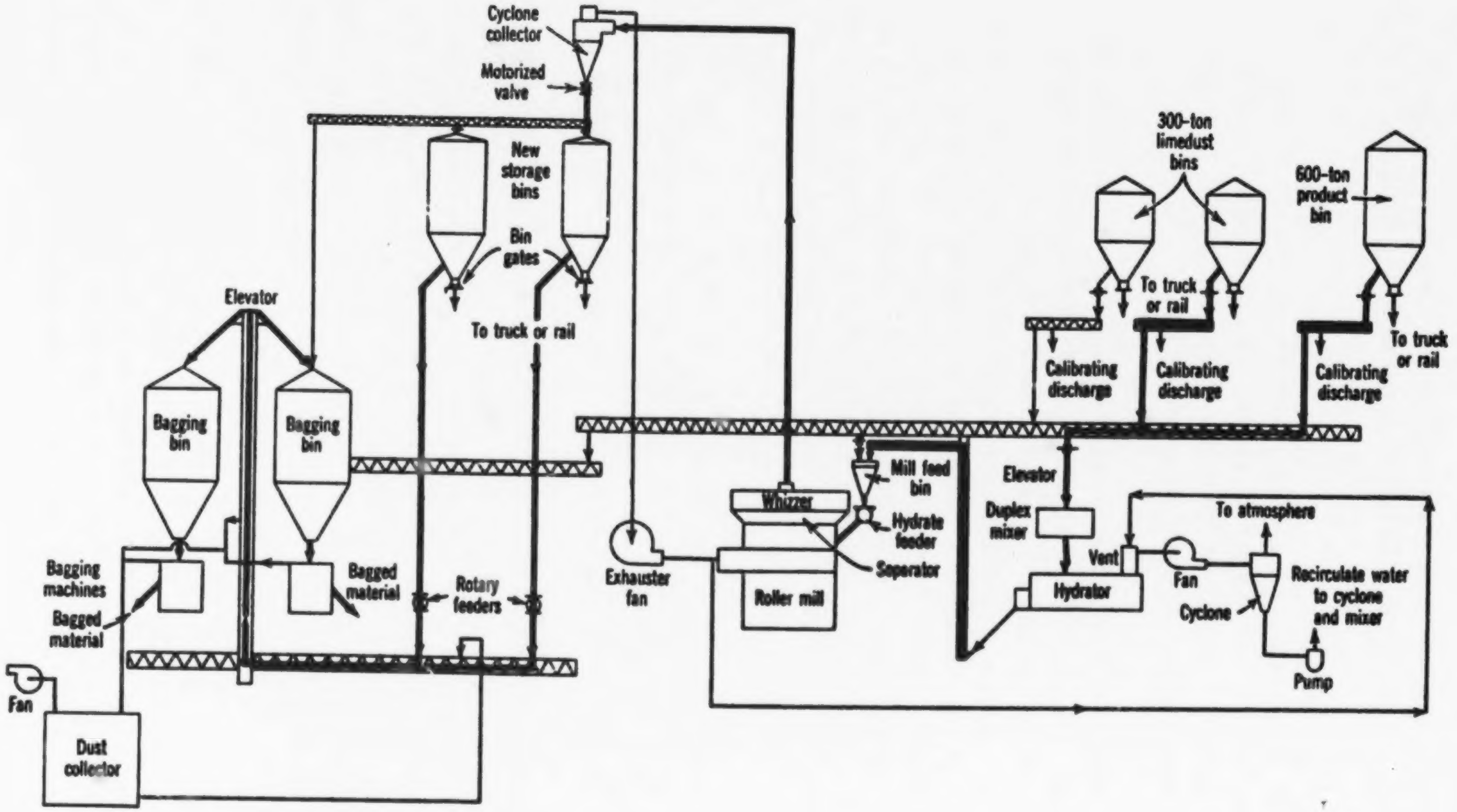

Figure 12-2 - Flow Diagram of a Modern Hydrated Lime Plant from Ground Quick Lime[2] Feed Silos Through to Bulk Hydrate Storage Silos and Bagging Department.

12.3 EMISSION SOURCES AND RATES

The major potential source of particulates in lime manufacture is the calcining kiln. Emissions vary with kiln type and the composition of limestone burned.

Vertical kilns do not produce as much dust as do rotary kilns because of the larger size of the limestone charged, the low gas velocities, and the smaller amount of attrition. Nevertheless vertical kilns are apt to be considered dusty by modern air pollution standards.

Rotary kilns constitute the largest single source of particulate matter in the lime industry. Abrasion of limestone in the kiln produces dust. The stone becomes more friable as it approaches the decomposition temperature, and dusting increases. Simultaneously with dusting from attrition, the high-velocity gases from direct-fire-fuel combustion blow the dust from the kiln. This is a vexing dust to control and collect. It is hot, dry, difficult to wet, and prone to be electrostatically charged. It is of mixed composition, varying all the way from raw limestone to final calcined product. It will also be mixed with fly ash, tars, and unburned carbon if pulverized coal is used as the fuel.

Dust blown from a kiln varies greatly with gas velocity. The literature reports doubling of the dust blown out when a kiln production rate was increased from 100 to 135% of design capacity, while dropping production rate to 75% of capacity decreased the dust loading only by 8%.3/

Data on dust emissions from new kiln processes are largely lacking. Grate-type kilns are stated to produce less dust than rotary kilns.2/ Fluo-solid kilns emit copious quantities of dust in the exhaust gases and require very efficient dust control equipment. Plants using the Calcimatic Process appear to be remarkably free of dust since the stone is stationary during calcination on a revolving hearth. The major sources of dust in this process are the exhaust from the stone preheater, the lime cooler, and the discharge lime conveyor.

The hydration of lime presents a potential dust problem. Steam and moisture laden air sweep fine dust from the hydrating operation into the exhaust stack. High calcium hydrators operate at ambient pressure with "lazy" exhaust gas velocity. Pressure dolomitic hydrators discharge steam, air, and product through small orifices to maintain the pressure created by the reaction, and thus impart a high velocity to the exit gases.

Secondary sources of particulate emissions include crushers, coolers, dryers, transfer points, and hydrate bagging operations.

12.3.1 Summary of Emission Rates

Table 12-1 presents a summary of particulate emissions from lime manufacture. Total emissions are about 573,000 tons/year. The emission factors for the lime kilns include emissions from coolers. Emission factors and net control for primary crushing operations are assumed to be the same as those quantities used for these operations in the crushed stone industry (Chapter 7). Emissions from fugitive sources such as stockpiles, traffic and wind action on road dust, leaky bins, and truck spillage have not been determined.

12.4 CHARACTERISTICS OF EFFLUENTS FROM LIME MANUFACTURE

The chemical and physical properties of effluents from lime plants are summarized in Table 12-2. About 30% of the dust from rotary kilns is less than 10 μ. The mean size is 30 μ and the geometric deviation is 7.5. Rotary kiln dust is difficult to wet and prone to be electrostatically charged. Particle shape data are summarized below:

(1) Limestone Dust - Mineral name: calcite. Colorless, with light-transmitting characteristics varying from transparent to translucent. Particles generally occur as rhombohedra because of their perfect rhombohedral cleavage. Fragments may also occur as prisms.

(2) Dolomite Dust - Mineral name: dolomite. In the pure state, dolomites are colorless and the fine particles are generally transparent to translucent.

(3) Lime Dust - Lime is usually white in color of varying shades but some may have a light cream, buff, or gray cast depending on the nature of the impurities in the lime.

12.5 CONTROL PRACTICES AND EQUIPMENT FOR LIME MANUFACTURE

Many plants in isolated areas carry out materials preparation operations with no control equipment or only the crudest kind of collection system.[3] Other plants collect the dust from exhaust systems with simple cyclones, water spray chambers, or baghouses.

The gases leaving a rotary kiln are usually first passed through a settling chamber to settle out the coarse particles. In some cases, dry cyclones may also be used for this primary collection. From 65-85% of the particulate matter may be collected here.[3] The major dust control problem is the dust passing the primary collector.

TABLE 12-1

PARTICULATE EMISSIONS
LIME MANUFACTURE

Source	Quantity of Material	Emission Factor	Efficiency of Control (C_c)	Application of Control (C_t)	Net Control ($C_c \cdot C_t$)	Emissions (tons/year
I. Kilns and Coolers	18,000,000 tons lime (excl. pulp & paper)					
A. Rotary Kilns and Coolers	16,200,000 tons	180 lb/ton lime	0.93	0.87	0.81	294,000
B. Vertical Kilns	1,800,000 tons	7 lb/ton lime	0.97	0.40	0.39	4,000
C. Fluid-Bed Kilns	---					
II. Minor Sources						
A. Stone Crushing and Screening						
1. Primary Crusher	28,000,000 tons of rock crushed for lime	22 lb/ton of rock crushed				
2. Secondary Crusher		2.0 lb/ton of rock crushed				
		24 lb/ton of rock crushed	0.80	0.25	0.20	264,000
3. Pulverizing, Quicklime			0.95	0.80	0.76	--
4. Milling, Hydrated Lime			0.95	0.80	0.76	--
B. Hydrator		--				
C. Materials Handling		--				
1. Conveyors						
a. Transfer Points						
b. Discharge to Bins, Stockpiles						
2. Elevators						
a. Boots		--				
b. Heads						
3. Shipment of Product						
a. Bagging Machines		--				
b. Bulk Loading		--				
(1) trucks						
(2) freight cars						
Assumed for hydrator plus materials handling		5 lb/ton of lime produced	0.95	0.80	0.76	11,000
				Total for Lime Manufacture		573,000

TABLE 12-2

EFFLUENT CHARACTERISTICS - LIME MANUFACTURE†

A. Particulate (Part 1)

Source	Particle Size	Solids Loading	Chemical Composition	Particle Density	Electrical Resistivity	Moisture Content	Toxicity
Lime Industry							
1. Limestone							
a. Crusher fan exhaust (1 test)		1.1-1.3	Limestone				
b. Raymond mill vent (1 test)	BAHCO analysis: 63 <5, 94.2 <10 98.5 <20		Limestone	2.5			
c. Hammer mill (1 test)	BAHCO analysis: 47 <5, 60 <10 74 <20, 86 <40		Limestone	2.8			
d. Screen house (1 test)	BAHCO analysis: 72 <5, 85 <10 95.5 <20, 98.8 <40		Limestone	2.7			
e. Stone dryer	BAHCO analysis: (2 tests) 20.5-68 <5, 30.5-87 <10, 38.6-93 <20, 45.5-96 <40 Microscope: Typical range: 31-50 <5, 91-93 <10, 95-99 <20. Avg.: 42 <5, 93 <10, 96 <20	4.3-11 Avg.: 8.5	Limestone				
f. Kiln preheater exhaust	BAHCO analysis: 9-28 <5, Avg.: 16 < 5; 15-40 <10, Avg.: 24 <10; 20-48 <15, Avg.: 29 <15; 30-63 <30, Avg.: 41 <30.		See rotary kiln	2.4-2.7			
g. Vertical kiln	10 <10, 50 <30	0.3-1.0	See rotary kiln				
h. Rotary kiln	BAHCO analysis: 10-36 <5, Avg.: 20 <5; 15-55 <10, Avg.: 28 <10; 21-73 <20, Avg.: 39 <20;26-91 <40, Avg.: 48 < 40 Microscope: Typical range: 46-70 <5, 74-94 <10, 85-95 <20. Avg.: 60 <5, 86 <10, 94 <20.	2-23, Avg.: 15	$CaCO_3$: 23-61; CaO: 6-66; Na_2CO_3: 1.4; $MgCO_3$: 1.4-18.7; Fe_2O_3,Al_2O_3: 2.9 Fly ash if kiln is coal-fired	2.6-3.0.	See Figure 12-3 for resistivity as a function of temperature		N.T., lime is irritating to eyes respiratory membranes and moist skin
i. Lime cooler	BAHCO analysis: 18.5 <5, 27 <10, 40 <20, 48 <40			3.0			
j. Calcimatic furnace	BAHCO analysis: 12.5 <5, 29.5 <10, 52.5 <20, 75 <40			3.3			
2. Dolomite							
a. Stone dryer		6.1-30.4					
b. Kiln	BAHCO analysis: 13-18 <5, Avg.: 16 <5; 21-29 <10, Avg. 25 < 10; 35-42 < 20, Avg. 39 < 20; 47-53 < 40, Avg.: 51 < 40.		(One sample) $CaCO_3$: 64; CaO: 7.2; MgO: 28.2; $CaSO_4$: 0.3. Acid insolubles: 0.45; R_2O_3: 0.35 (heavy metal oxides)	2.8.			
3. Hydrated lime							
a. Hydrator (1 test)	BAHCO analysis: 62 <5, 75 <10, 83 <20, 90 <40			2.5			
b. Pulverizer exhaust (1 test)	BAHCO analysis: 52 <5, 93 <10, 96.3 <20, 99.8 <40			2.4			
c. Bagging bin vent (1 test)	BAHCO analysis: 71 <5, 87.3 <10, 96 <20, 98.8 <40			2.1			

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† See Coding Key, Table 5-1, Chapter 5, page 45, for units for individual effluent properties.

TABLE 12-2 (Concluded)

A. Particulate (Part II)

Source	Solubility	Wettability	Hygroscopic Characteristics	Flammability or Explosive Limits	Handling Characteristics	Optical Properties	Odor
Lime Industry							
1. Limestone							
a. Rotary kiln	$CaCO_3$ - s. H_2O, acid; CaO - d. H_2O; MgO - s. sl. H_2O, s. acid; $CaSO_4$ - s. sl. H_2O, s. acid	Difficult to wet					

B. Carrier Gas

Source	Flow Rate	Temperature	Moisture Content	Chemical Composition	Toxicity	Corrosivity	Odor	Flammability or Explosive Limits	Optical Properties
Lime Industry									
1. Limestone									
a. Crusher fan exhaust (1 test)	a) 18.2								
b. Raymond mill vent									
c. Hammer mill									
d. Screen house									
e. Stone dryer (1 dryer)	a) 14.7*	110							
f. Kiln preheater exhaust									
g. Vertical kiln (1 kiln)	a) 33.5*								
h. Rotary kiln	b) 57-204* (Function of fuel/lime ratio)	600-1800; typical exhaust temp. for 6 ft. diam. kiln is 1350°F "80" ft. of length		CO_2, O_2, N_2, H_2O, SO_2	SO_2 - 5, irritant				
i. Lime cooler									
j. Calcinatic furnace									
2. Dolomite									
a. Stone dryer	b) 36-43*	127-199	10-15						
b. Kiln				CO_2, O_2, N_2, H_2O, SO_2	SO_2 - 5, irritant				
3. Hydrated Lime									
a. Hydrator									
b. Pulverizer exhaust									
c. Bagging bin vent									

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* Actual cubic feet.

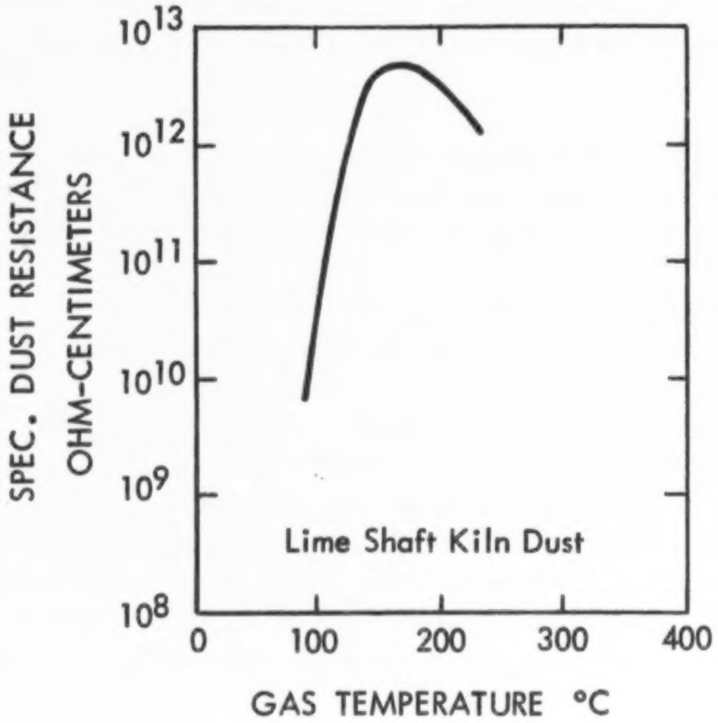

Figure 12-3 - Dependence of Specific Electrical Dust Resistance on Gas Temperature for Lime Shaft Kiln Dust [7]

Plants in some areas have installed high-efficiency cyclonic secondary collectors on their kiln operations. Table 12-3 lists data on a number of installations with secondary collectors. However, to meet emission requirements plants are increasingly turning to wet scrubbers and glass bag collectors. Electrostatic precipitators have also been found satisfactory. However, economics in the lime industry are such that precipitators are generally not installed as long as scrubbers and bag collectors give acceptable performance. Table 12-4 presents the estimated cost of three basic types of control equipment for a rotary kiln.[6] The control equipment costs are listed for two different efficiencies. These costs compare closely with general cost data given in Appendix A, except that the fabric-filter operating cost of $14,000 is about double the typical value computed from Appendix A.

When making cost estimates of a collector system, the precooling or preconditioning section that may be required must be included. This can be very significant for baghouses and electrostatic precipitators.

Lime-hydrating processes can also be an important source of dust emissions. The loss of hydrated-lime dust represents loss of valuable product since the dust is high purity. It is easily wetted and can be scrubbed from the stack gases with a water scrubber. The recovered water slurry can be fed back to the hydrator as make-up water. Venturi-type scrubbers or other commercial wet scrubbers are used for this service. Effluent loadings of 0.01-0.07 grain/cu ft are reported.[3,4] Table 12-5 presents data and costs reported for control equipment associated with various hydrate operations.[6] Dryers also present a difficult dust control operation in a lime or limestone plant. Table 12-6 contains data and costs for control equipment associated with this operation.[6]

12.5.1 Cyclone Collectors

High-efficiency cyclones are suitable as primary collectors and precleaners for removal of the +10 μ size dust. One installation reports handling 80,000 acfm of kiln gas at 450-500°F and 30-35% moisture content in 72 9-in. size cast iron cyclones with a pressure drop of 2-1/4 in. of water and 70% collection efficiency.[3]

12.5.2 Bag Filters

A number of installations are reported making use of glass fiber bag collectors handling gas flows as high as 150,000 acfm at temperatures in the range of 350-550°F, with average particle sizes of 25 μ after precleaning with dust settlers. For the larger gas volumes the baghouse is compartmented so that only one section at a time is cleaned. A 12-compartment baghouse for a 500 ton/day kiln has been reported. The cleaning cycle (shaking is not employed with glass bags) depends on dust loading but is

TABLE 12-3

SECONDARY COLLECTION OF ROTARY KILN LIME DUST[3]

Installation No.: Primary Collection Type of Secondary Collector	1 Dust Chambers Glass Bag Collectors	2 Dust Chambers 4-Stage Cyclonic Dynamic Scrubber	3 Dust Chambers 4-Stage Cyclonic Dynamic Scrubber	4 9-In. Tube Cyclones[a] Single Stage Electrostatic Precipitator	5 Dust Chambers Venturi Scrubber and Cyclonic Scrubber	6 Dust Chambers Spray and Impingement Plate Scrubber
Inlet loading grains/scfm	10.0	2.8-2.9	9.5	4.3	4-7	16
Outlet loading grains/scfm	0.001	0.071-0.080	0.02	0.22	0.12	0.3-0.4
Collection efficiency	99.99%	97.5%	99.7%	95%	97-96.3%	97.5%
Pressure drop in secondary collector--inches of water	4-5	8	8	1-2	15	5-6

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[a] Primary collector consists of 9-in. tube cyclones. Inlet loading to cyclones, 14.5 grains/cu ft; outlet loading, 4.3 grains/cu ft; efficiency, 70%.

TABLE 12-4

ESTIMATE OF ROTARY KILN CONTROL COSTS[6/]

Capacity - 350 tons/day
Exhaust Gas Volume - 100,000 cfm
Exhaust Gas Temperature - 550°F
Power Cost - $0.01/kwh

Type of Collector	Installed Cost of Unit	Operating Cost/Year	Maintenance Cost/Year
	For 99% Efficiency		
Baghouse	$150,000	$14,000	$8,000
Electrostatic Precipitator	200,000	2,300	2,000
Scrubber	60,000	65,000	6,000
	For 97% Efficiency		
Baghouse	$150,000	$14,000	$8,000
Electrostatic Precipitator	100,000	2,300	2,000
Scrubber	50,000	30,000	6,000

TABLE 12-5[6/]

HYDRATOR

Type of System	Air Flow (cfm)	Filter Area (sq. ft.)	Air-Cloth Ratio	No. of Bags	No. of Compartments	Capital and Installed Cost	Type of Application
Bag Filter	13,000	1,750	-	128	-	$19,000	Bagging
Bag Filter	11,000 (5 in. w.g.)	9,660	-	112	-	30,000	Fines from cyclone
Bag Filter	-	1,668	3.55:1	-	-	9,500	Fines from pre-cleaner
Bag Filter	5,000	1,050	-	-	-	-	-
Bag Filter	10,000	-	-	-	3	30,000	Bagging
Bag Filter	14,850	-	-	-	-	-	-
Bag Filter	4,250	-	-	43	-	-	Bagging
Bag Filter	6,000	576	-	-	-	-	Bagging
Bag Filter	5,000	1,050	-	-	-	10,000	Quicklime grinding
Bag Filter	2,500 (150°F)	344	-	-	-	16,000	Raymond Mill
Scrubber	-	-	-	-	-	9,500	-
Cyclone Pre-cleaner	-	-	-	-	-	10,000	-

Note: Bags used are cotton, dacron, and glass; dacron most common.

TABLE 12-6[6]

STONE DRYERS

Plant	Collecting System	Cloth-Area (sq. ft.)	No. of Bags	No. of Compartments	Air Flow (cfm)	Efficiency	Capital and Installed Cost
1	Cyclone and Baghouse	2,550	360	-	15,000 at 220°F	-	\$10,000 Cyclone 36,000 Baghouse
2	Baghouse	6,250	112	4	4,500-7,500 at 12 in.	-	20,000
3	Primary, Secondary Cyclone and Baghouse	3,120	312	8	18,100 at 230°F	99+%	50,000
4	Cyclone (only)	-	-	-	8,800	(508 lb/hr)	12,000
5	2-Stage Cyclone and Hi-Energy Scrubber	(400 gpm H_2O)	-	-	50,000 at 30 in.	99.9%	215,000

usually a 10-15 min. cycle. Design air-to-cloth ratio with one compartment out for cleaning is in the range of 1.95:1 to 2.2:1. Since kiln gases are frequently discharged hotter than can be handled directly by the bags, it is usual practice to cool the gases by water spray, air dilution, or a combination. Insulation of the baghouse is not usually required unless the moisture content of the gases is quite high, as might be the case with wet feed. Bag life up to 2 years is reported. Collection efficiency is almost 100% between bag cleanings because a thin layer of dust on the bag forms an additional filtering media. Particles 5 μ and less in size are apt to be lost through the bag immediately after cleaning. Capital cost is reported to be $1.80/cfm handled, with annual operating plus maintenance costs running $0.20/cfm.3/

The capital cost of $1.80/cfm agrees reasonably well with the higher cost curves of installed cost for fabric filters given in Appendix A. Annual operating and maintenance cost of $0.20/cfm corresponds to the "high" values given in Appendix A but this cost is largely a function of power cost.

12.5.3 Electrostatic Precipitators

While the use of electrostatic precipitators tends to be costly for the lime industry, one installation has been reported using a single stage precipitator as a secondary collector at a capital cost of $1.25/cfm. It handles 160,000 cfm at 450-500°F inlet conditions in which 90-95% of the inlet dust is -10 μ. It is designed with a gas velocity of 3.3 ft/sec and a resident time of 5.2 sec. and has an on-stream efficiency of 95%.3/

12.5.4 Wet Scrubbers

One of the advantages of a wet scrubber is that it can include a pre-humidification section and eliminate the need for pre-cooling the gases. A typical installation for a 180-200 ton/day kiln with 40-50,000 acfm at 900-1400°F and a 5-10 grains/cu ft dust loading, would require a 9-10 ft. diameter scrubber 32 ft. tall. Scrubbing water requirement is 4 gal/1,000 cu. ft. of gas processed. Pressure drop is 8 in. of water. For the 200 ton/day kiln installation, fan brake horsepower would be 150. Collection efficiency is stated to be 99.7%. Scrubber cost is reported to be $0.50/cfm of cooled saturated exhaust gas for 304 stainless steel construction and $0.25/cfm for carbon steel.3/ The cost for carbon steel construction compares closely with purchase cost in Appendix A.

A dust removal efficiency of 96-97% has been reported for a 335 ton/day kiln using a combination Venturi scrubber and cyclonic separator. A pressure drop of 7-11 in. water was used. Inlet gas volume was 60-62,000 cfm at 350°F. Water supplied to the Venturi throat was 1,500 gpm at 50 psig pressure. Cleaned exhaust gases were discharged at 160-165°F nearly saturated with water vapor.3/

While wet scrubbing may frequently be cheaper, problems can occur which are not present with dry collection. Examples are discharge of a hot humid gas, scale buildup, and corrosion. The presence of sulfur oxides may dictate the use of corrosion resistant alloys for wetted parts including the exhaust fan. Some producers report operating costs for a wet scrubber three times as great as for a bag filter even though initial cost is considerably less. The scrubber slurry is also a potential water pollutant if not properly confined or consumed.3/

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CHAPTER 13

PRIMARY NONFERROUS METALLURGY

13.1 INTRODUCTION

Primary nonferrous metallurgy, as used here, will include smelting and refining of copper, lead, zinc, and aluminum. The air pollution problems of the nonferrous metallurgical industry are extremely varied. However, one typical characteristic exists--in almost all the processes in the production of nonferrous metals, the particulates emitted are metallic fumes generally submicron in size. Table 13-1 summarizes particulate emissions from the primary nonferrous metals industry.

The production processes, particulate emission sources, particulate emission rates, effluent characteristics, and control practices and equipment for copper, lead, zinc and aluminum smelting and refining are discussed in the following sections.

13.2 PRIMARY COPPER SMELTING AND REFINING

Copper is obtained from copper ores by smelting. The term "smelting" can be used, in a wide sense, to cover the successive operations of roasting, reverberatory smelting, coverting, and fire refining. Although there are considerable variations in practice from smelter to smelter, the basic principles are essentially the same. A simplified flow diagram of a typical smelter operation is shown in Figure 13-1.

The ores are smelted down either as they come from the mine or are subjected (in particularly the sulfur-containing copper ores) to a preparatory process of grinding and flotation. This transforms the low-percentage ores into a high-percentage copper/sulfur concentrate. The latter is subsequently smelted down either directly or after partial roasting. Roasting removes part of the sulfur giving a favorable balance of copper, iron, and sulfur for the reverberatory feed. In the reverberatory furnace the iron present as oxide combines with siliceous flux to form a slag, leaving a material known as matte, which contains copper, iron, and some sulfur, preferably combined with the copper. The matte is reduced to copper in the converter in two stages of blowing with air. The first stage eliminates sulfur, and forms the iron oxide which is slagged off by the addition of siliceous flux. The copper sulfide remaining in the converter is reduced to metal and the sulfur is eliminated as SO_2 in the "finish" blowing stage. The copper at this stage is called blister copper. This crude copper undergoes further refinement by fire refining to reduce the sulfur and oxygen, and then is cast into anodes for electrolytic refining.

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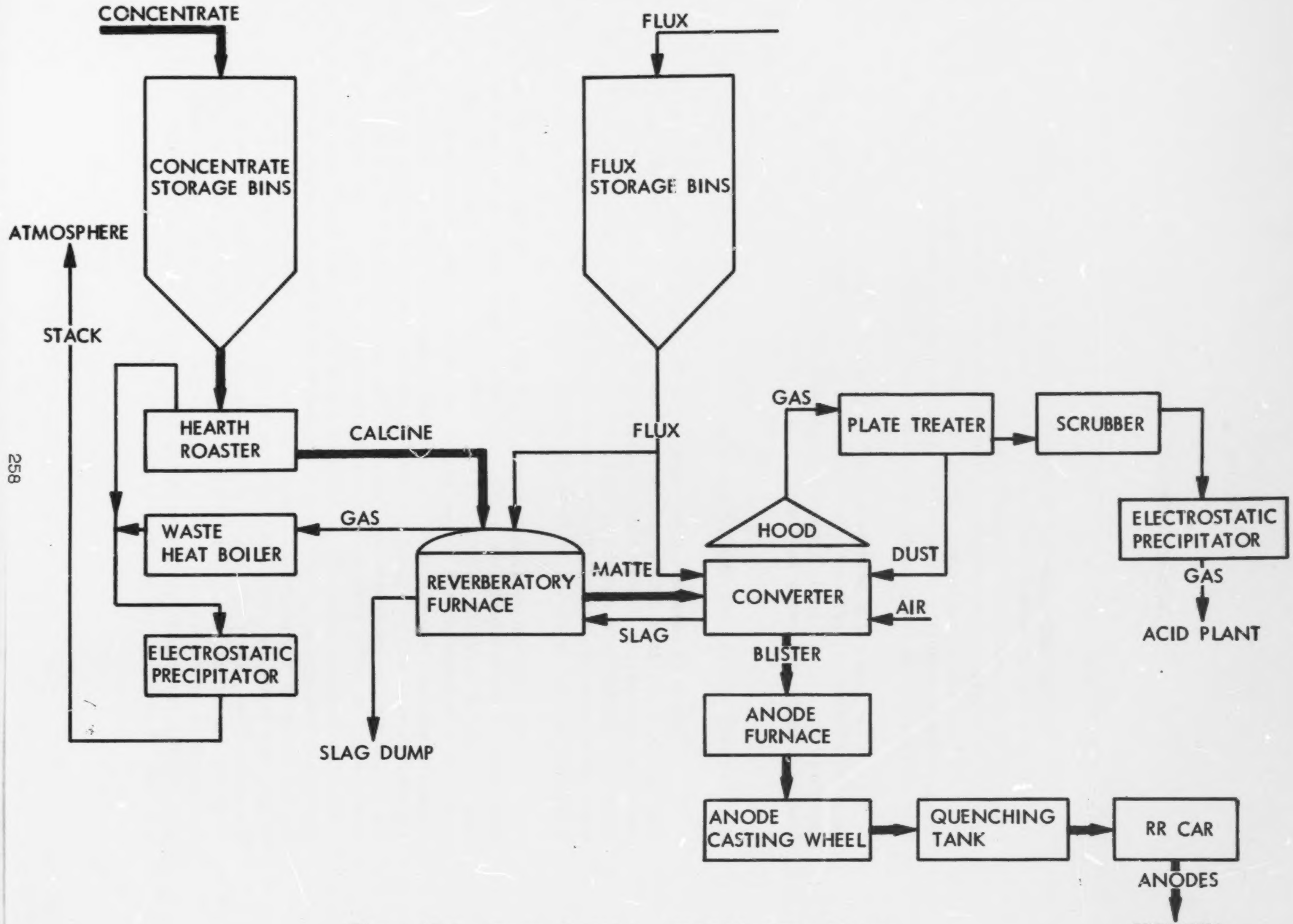

Figure 13-1 - Copper Smelting - Simplified Flow Diagram

13.2.1 Emission Sources and Rates

Dust is emitted from all pyrometallurgical operations. The various phases of the process and their particulate emission potential are discussed briefly in the following sections.

13.2.1.1 Roasting: Copper roasting at smelters in the U. S. is slowly being phased out. The older multiple-hearth roasters have been abandoned in some plants in favor of more modern equipment.

Recent installations are generally fluid-bed roasters. These have been in use in copper smelters for about 10 years. The feed material may be sprayed into the top of the roaster as a water slurry or charged as a solid.

Multiple-hearth roasters usually operate at a temperature of about 1200°F. Sulfur dioxide concentration in the wet off gas is usually only 5 to 10% because of low efficiencies in the furnace and dilution by air. The dust load in the off gas is around 3 to 6% of the weight of the feed, and a large portion of the dust is recovered in the flues.

Fluid-bed roasters operate in the same temperature range as multiple-hearth roasters. However, about 85% of the feed is carried in the gas stream, and most of it is immediately recovered in cyclone collectors. The wet off gas runs 12 to 14 vol. % sulfur dioxide.

After preliminary solids collection, the gas from either type of roaster is cooled to 600°F by air dilution, water sprays, or heat exchangers before the final cleaning.1/

The dust content of the waste gases depends on the characteristics of the copper concentrates as well as on the volume of air aspirated by the roasting furnace. Another factor of importance in hearth furnaces is the extent to which the concentrates remain continuously in suspension when descending from the upper to the lower hearths. The size and number of the apertures in the hearths has an influence on the creation of dust in the furnace, and consequently also on the dust content of the waste gases.

13.2.1.2 Reverberatory Furnaces: The reverberatory furnace melts the metal-bearing charge and forms the matte and slag. The charge is introduced through openings in the side wall or in the roof.1/

Collection and recovery of dust from the furnace gas is a substantial problem. The heavier particles settle below the waste heat boilers, and into the hoppers of the balloon flues or settling chambers. Practically all copper smelters have a main collector system that includes drag or screw conveyors that remove the dust from the various places where it accumulates. The dust is then moved to locations where it can be worked back into the system. The amount of dust will depend upon variables such as the fineness of the charge, the degree of agitation in charging and working, and specific gravity.

13.2.1.3 Copper - Matte Converter: Molten matte produced in the reverberatory furnace is transferred in ladles to the converters by overhead cranes. The function of the converters is to oxidize and separate the iron and sulfur from the matte. Air is blown into the liquid matte through openings called "tuyeres." The oxidation reactions supply enough heat to maintain the converter at a temperature of about 2250°F and no fuel is required. The sulfur dioxide is carried out with the other flue gases. Silica flux is added to combine with the iron oxide to form a fluid iron silicate slag. The slag is skimmed from the converter and returned to the reverberatory furnace. Additional matte is added to the converter and the process repeated until a suitable charge of copper sulfide has been accumulated. Blowing is then continued without further matte additions until the remaining sulfur has been eliminated. The resulting blister copper is usually more than 99% pure. It is removed from the converter to be cast or further refined.

Dust loads in converter gases may amount to 10 to 20 tons/day/unit. About 75 to 85% of these solids settle in the flue system. The remaining 15 to 25%, composed of the smaller particles, is largely removed in dust collectors.1/

The dust content of the gases depends to a large extent on the chemical composition of the copper matte. An increase in the operating temperature of the converter causes higher volatilization of the metals and consequently higher dust content in the raw gas.

13.2.1.4 Fire Refining: Blister copper, the end product of the converter, contains about 0.04% sulfur and requires further refining in order to meet most purity specifications for fabricated copper products. Of the 16 copper smelters in the U.S., five produce blister copper only. The others fire-refine part or all of the blister copper for anodes or other shapes.1/

Furnaces commonly used are either of the reverberatory or tilting cylindrical type. The type of furnace used depends on the operational continuity at the particular plant.

13.2.1.5 Summary of Emission Rates: Table 13-1 summarizes the emission rates from the various processes involved in the production of primary copper. Limited data on control efficiency and degree of application of control were found. The emission totals in Table 13-1 are considered as conservative estimates.

13.2.2 Characteristics of Effluents from Primary Copper Production

The chemical and physical properties of effluents from primary copper smelters are summarized in Table 13-2. Particulate emissions from the furnaces are predominantly metallic fumes of submicron size. The fumes are difficult to wet and readily agglomerate. In addition, they are cohesive and will bridge and arch in hoppers and other collection bins.

13.2.3 Control Practices and Equipment for Copper Smelting and Refining

Copper sulfide concentrates received at the smelter are normally roasted in multiple-hearth roasters to remove moisture, to burn off part of the contained sulfur, and to preheat the material before smelting.

One copper smelter is using a fluidized roaster, and the gases are cleaned in a Peabody scrubber prior to entering the sulfuric acid manufacturing process.3/ In recent years the roasting step has been eliminated at many smelters.4/

The value of volatilized elements, as well as air pollution considerations, dictates efficient collection of fumes and dusts from process off gases. Balloon flues may serve as gravity collectors, and cyclones may be used also. For collection of the finer particulates, electrostatic precipitators are most often used. Collection efficiencies up to 99.7% for copper dust and fume are attained by careful conditioning of flue gases.4/

One installation which used an electrostatic precipitator to clean the gases from a copper smelter has been described. This system was revised to separately clean the roaster, reverberatory and converter gas streams in the electrostatic precipitator system. A baghouse was added for further cleaning of the combined reverberatory and converter gas streams at the exit of the precipitator.14/

TABLE 13-1

PARTICULATE EMISSIONS
PRIMARY NONFERROUS METALS INDUSTRIES

	Quantity of Material	Emission Factor	Efficiency of Control (C_c)	Application of Control (C_t)	Net Control ($C_c \cdot C_t$)	Emissions (tons/yr)
I. Aluminum						
A. Preparation of Alumina						
1. Grinding of Bauxite	13,000,000 tons of bauxite	6 lb/ton of bauxite	-	-	0.80	8,000
2. Calcining of Hydroxide	5,840,000 tons of alumina	200 lb/ton of alumina	-	-	0.90	58,000
B. Aluminum Mills						
1. Soderberg Cells						
a. Horizontal stud	800,000 tons of aluminum	144 lb/ton of aluminum	0.40	1.0	0.40	35,000
b. Vertical stud	700,000 tons of aluminum	84 lb/ton of aluminum	0.64	1.0	0.64	10,000
2. Pre-Bake Cells	1,755,000 tons of aluminum	63 lb/ton of aluminum	0.64	1.0	0.64	20,000
C. Materials Handling	3,300,000 tons of aluminum	10 lb/ton of aluminum	0.90	0.35	0.32	11,000
	Total from primary aluminum industry					142,000
II. Copper						
A. Ore Crushing	170,000,000 tons of ore	2 lb/ton of ore	0.0	0.0	0.0	170,000
B. Roasting	40% of 1,437,000 tons of copper	168 lb/ton copper	0.85	1.0	0.85	7,000
C. Reverberatory Furnace	1,437,000 tons of copper	206 lb/ton copper	0.95	0.85	0.81	28,000
D. Converter	1,437,000 tons of copper	235 lb/ton copper	0.95	0.85	0.81	33,000
E. Fire Refining						
F. Slag Furnaces						
G. Materials Handling: Ore, Limestone Slag, etc.	1,437,000 tons of copper	10 lb/ton copper	0.90	0.35	0.32	5,000
	Total from primary copper industry					243,000
III. Zinc						
A. Ore Crushing	18,000,000 tons of ore	2 lb/ton of ore	0.0	0.0	0.0	18,000
B. Roasting						
1. Fluidized-Bed, Suspension	75% of 1,020,000 tons of zinc	2,000 lb/ton zinc	0.98	1.0	0.98	15,000
2. Ropp, Multiple-Hearth	15% of 1,020,000 tons of zinc	333 lb/ton zinc	0.85	1.0	0.85	4,000
C. Sintering and Sinter Crushing	60% of 1,020,000 tons of zinc	180 lb/ton zinc	0.95	1.0	0.95	3,000
D. Distillation	60% of 1,020,000 tons of zinc		0.0	0.0	0.0	15,000
E. Materials Handling	1,020,000 tons of zinc	7 lb/ton zinc	0.90	0.35	0.32	2,000
	Total from primary zinc industry					57,000
IV. Lead						
A. Ore Crushing	4,500,000 tons of ore	2 lb/ton ore	0.0	0.0	0.0	4,000
B. Sintering	467,000 tons of lead	520 lb/ton lead	0.95	0.90	0.86	17,000
C. Blast Furnace	467,000 tons of lead	250 lb/ton lead	0.85	0.98	0.83	10,000
D. Drossing Kettle		-				
E. Softening Furnace		-				
F. De-Silvering Kettles		-				
G. Cupeling Furnaces		-				
H. Refining Kettles		-				
I. Dross Reverberatory Furnace	467,000 tons of lead	20 lb/ton lead	-	-	0.50	2,000
J. Materials Handling	467,000 tons of lead	5 lb/ton lead	0.90	0.35	0.32	1,000
	Total from primary lead industry					34,000
	Total from nonferrous metals industries					476,000

TABLE 13-2

EFFLUENT CHARACTERISTICS
PRIMARY NONFERROUS METALS INDUSTRIES[+]

A. Particulate (Part 1)

Source	Particle Size	Solids Loading	Chemical Composition	Particle Density	Electrical Resistivity	Moisture Content	Toxicity
Primary Nonferrous Metals							
1. Copper							
a. Roasting furnace	15 < 10	6-24	Cu: 9, S: 10, Fe: 26*				
b. Blast furnace		6.6*	Cu: 4.4, Zn: 12.5, S: 7.3*				
c. Reverberatory furnace	51 < 37	1-6	Cu: 6.2, Zn: 13.0, S: 13.6* Traces of elements corresponding to composition of ore: Oxides of arsenic, antimony, aluminum silicon sulfates.				
d. Copper matte converter		5.3*	Cu: 1.2, Zn: 18.0, S: 10* (also see reverberatory furnace)				
e. Copper refining furnace (coal dust fired)	50 < 44		Cu: 7, S: 1.5*				
2. Lead							
a. Sinter machine		0.87-6.6*	Pb: 40-65, Zn: 10-20, S: 8-12* Traces of elements corresponding to composition of mixture; oxides of arsenic, cadmium, selenium, and tellurium. Also gold and silver.		See Figures 13-2 and 13-3 for detailed data		Pb: 0.15 Zn: 15
b. Blast furnace	0.03-0.3	1-11	Sulfates, oxides, lead sulfide, coke dust, PbO, ZnO, CdO, Pb_3O_4.		See Figure 13-4 for detailed data		
c. Reverberatory furnace		0.4-4.4*					
d. Short revolving reverberatory furnace		1.3-8.8*					
3. Zinc							
a. Roaster	Unspecified Roaster, Bahco Analysis: 14 <5, 31 <10 70 <20	5-65					
(1) Ropp roaster			ZnS	5.7			
(2) Multiple-hearth roaster							
(3) Suspension roaster							
(4) Fluid-bed roaster							
(5) Fluid-column roaster							
b. Sinter machine	100 <10*	0.4-4.5	Zn: 5-25; Pb: 30-55, Cd: 2-15, S: 8-13				
c. Horizontal retort	Micron to submicron	0.04-0.13*	Zn: 50-70*, Pb: 0-3		Figures 13-5 and 13-6 give resistivity for slag fuming plant and melting plant		ZnO: 15
d. Vertical muffle furnace	100 <10*	0.9*	Zn: 68-70*, Pb: 4-5				
e. Rotary furnace	90 <10*	9-22*	Zn: 65, Pb: 8, S: 1.5				

[+] See Coding Key, Table 5-1, Chapter 5, p. 45, for units for individual effluent properties.
* German data.

TABLE 13-2 (Continued)

A. Particulate (Part I)(Concluded)

Source	Particle Size	Solids Loading	Chemical Composition	Particle Density	Electrical Resistivity	Moisture Content	Toxicity
4. Aluminum							
a. Bauxite dryer	10-30 < 10	20-60					
b. Bauxite kiln	Bahco Analysis 10-16 <5 Avg. 13 <5 20-29 <10 Avg. 25 <10 31-43 <20 Avg. 37 <20 43-55 <40 Avg. 49 <40	100-300	Al_2O_3 ≥ 99 SiO_2: 0.005-0.015 Fe_2O_3: 0.005-0.02 Na_2O: 0.4-0.80			Combined H_2O 0.05-0.15 Adsorbed H_2O 0.20-0.50	
c. Reduction cell	Range in size down to submicron levels	0.03-2.0	Al_2O_3, tar, carbon, fluorides, and various impurities Also see Table 13-3				
d. Refining and casting furnaces	Range in size down to submicron levels	2-20 (High value during chlorine fluxing)	Al_2O_3, $AlCl_3$, impurities Also see Table 13-4				Acidic

A. Particulate (Part II)

Source	Solubility	Wettability	Hygroscopic Characteristics	Flammability or Explosive Limits	Handling Characteristics	Optical Properties	Odor
1. Copper Refining		Difficult to wet			Agglomerates, cohesive, will bridge and arch		
2. Lead Refining		" "			" "		
3. Zinc Refining		" "			" "		
4. Aluminum Refining	$AlCl_3 - s\ H_2O$				Corrosive, abrasive		

B. Carrier Gas

Source	Flow Rate	Temperature	Moisture Content	Chemical Composition	Toxicity	Corrosivity	Odor	Flammability Limits	Optical Properties
Primary Nonferrous Metals									
1. Copper									
a. Roasting furnace	a) 60-131 b) 47.3*	600-890		SO_2: 8*					
b. Blast furnace	a) 21.2 b) 76.5*	248*	-	CO_2: 6.5*					
c. Reverberatory furnace	a) 50-460 b) 71*	350-750	4-10	O_2: 5-6, CO_2: 10-17, N_2: 72-76, CO: 0-0.2, SO_2: 1-2					
d. Copper matte converter	a) 102-750* b) 364*	300-650		SO_2: 4*					
e. Copper refining furnace (coal dust fired)	a) 16*	410*							

TABLE 13-2 (Concluded)

B. Carrier Gas (Concluded)

Source		Temperature	Moisture Content	Chemical Composition	Toxicity	Corrosivity	Odor	Flammability Limits	Optical Properties
2. Lead									
a. Sinter machine	a) 140** b) 130**	250-600		SO_2, O_2, N_2, CO_2, H_2O, possible traces of HF and SiF_4					
b. Blast furnace	a) 6-14 195** b) 180**	150-250		Typical analysis: CO_2: 4.7, O_2: 15.0, CO: 1.3, SO_2: 0.14 N_2: balance					
c. Reverberatory furnace	a) 1-3 b) 3.5-17.5*	1400-1800 (Furnace outlet)							
d. Short revolving reverberatory furnace	b) 35.3-106*								
3. Zinc									
a. Roaster									
(1) Ropp roaster	a) 25-30	730-900		SO_2: 0.7-1.0, O_2, N_2, CO_2, and H_2O					
(2) Multiple-hearth roaster	b) 5-6	500-520		SO_2: 4.5-6.5, O_2, N_2, CO_2 and H_2O					
(3) Suspension roaster	a) 10-15	550-600		SO_2: 10-13, O_2, N_2, CO_2, and H_2O					
(4) Fluid-bed roaster	a) 6-10			SO_2: 7-12, O_2, N_2, CO_2 and H_2O					
(5) Fluid-column roaster				SO_2: 11-12, O_2, N_2, CO_2 and H_2O					
b. Sinter machine	b) 140*	320-700	Dew Point* 122-140	SO_2: 4.5-7*	SO_2: 5 Irritant				
c. Horizontal Retort	a) 3,400-5,100 (condenser waste gas including extraneous air) b) 420-640* (flue gas)			 CO_2: 12-17*					
d. Vertical muffle furnace	b) 740*			CO_2: 2.5-3.0*					White smoke
e. Rotary	b) 88-530*	1,000-1,300		CO_2: 10*					
4. Aluminum									
a. Bauxite dryer	a) 100-150	150-350	30-35						
b. Bauxite kiln	a) 25-135	250-720	40-50	CO_2, O_2, N_2, H_2O					
c. Reduction cells	Of the order 2-4,000 cfm/cell 10^6 cfm/potline			O_2, N_2, CO, SO_2, fluorides, hydrocarbons.	SO_2: 5, irritant CO: 100 HCl: 5 Cl_2: 1 Fluorides: toxic	Acidic, corrosive			
d. Refining and casting furnace		Furnace Discharge: 1300-1800 Stack Discharge: 200-500		CO_2, O_2, N_2, H_2O (prior to Cl_2 fluxing) CO_2, O_2, N_2, H_2O, HCl, Cl_2 (during Cl_2 fluxing)		Acidic, corrosive (during Cl_2 fluxing)			Dense, white plume during chlorine fluxing

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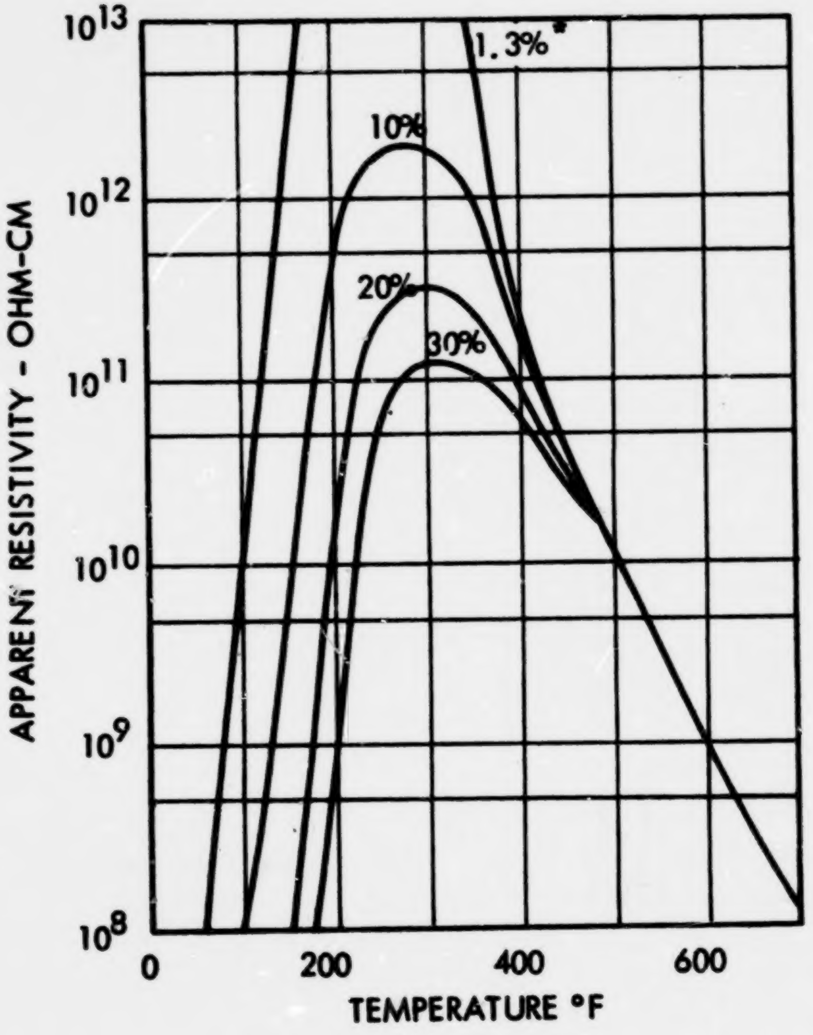
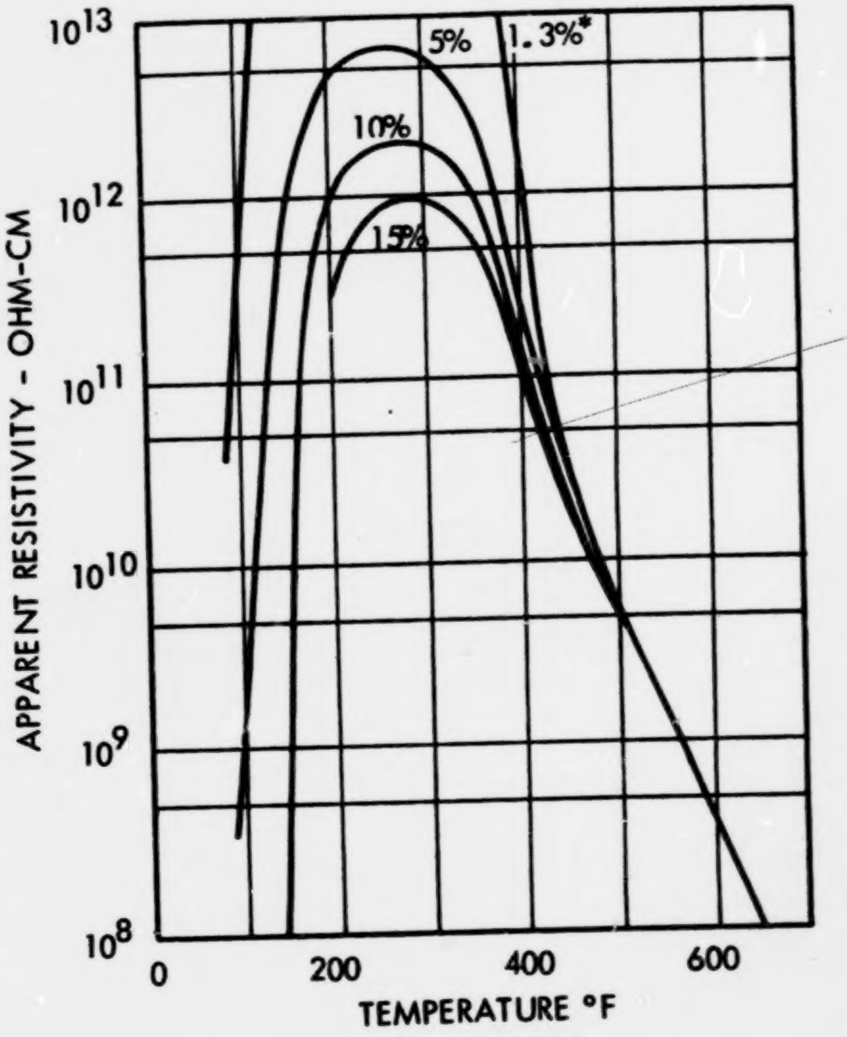
* German data.

** Canadian data.



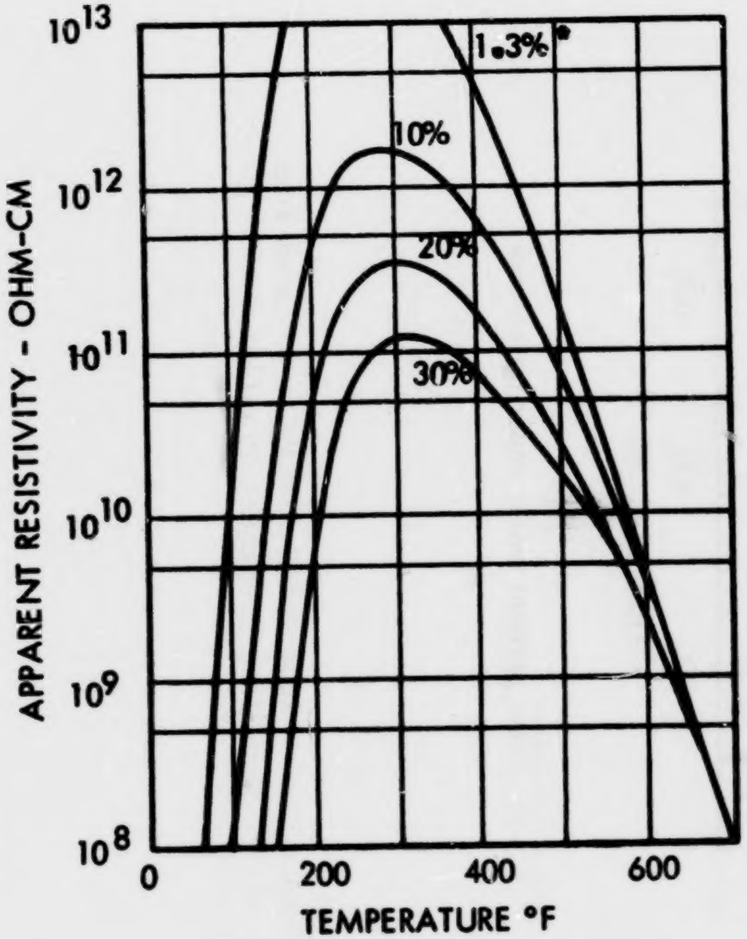
* Figure shows percent water vapor by volume.

Figure 13-2 - Typical Resistivity Graph of Lead Fume 16/



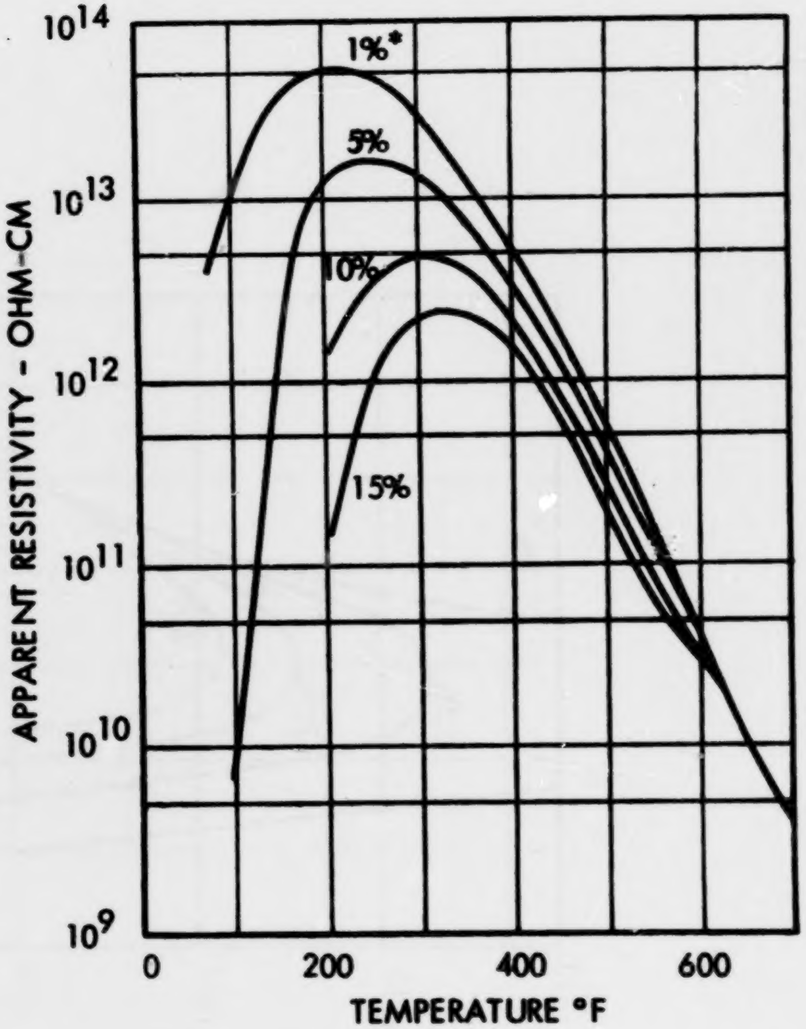
* Figure shows percent water vapor by volume.

Figure 13-3 - Apparent Resistivity of Lead Fume from Sintering Plant 17/



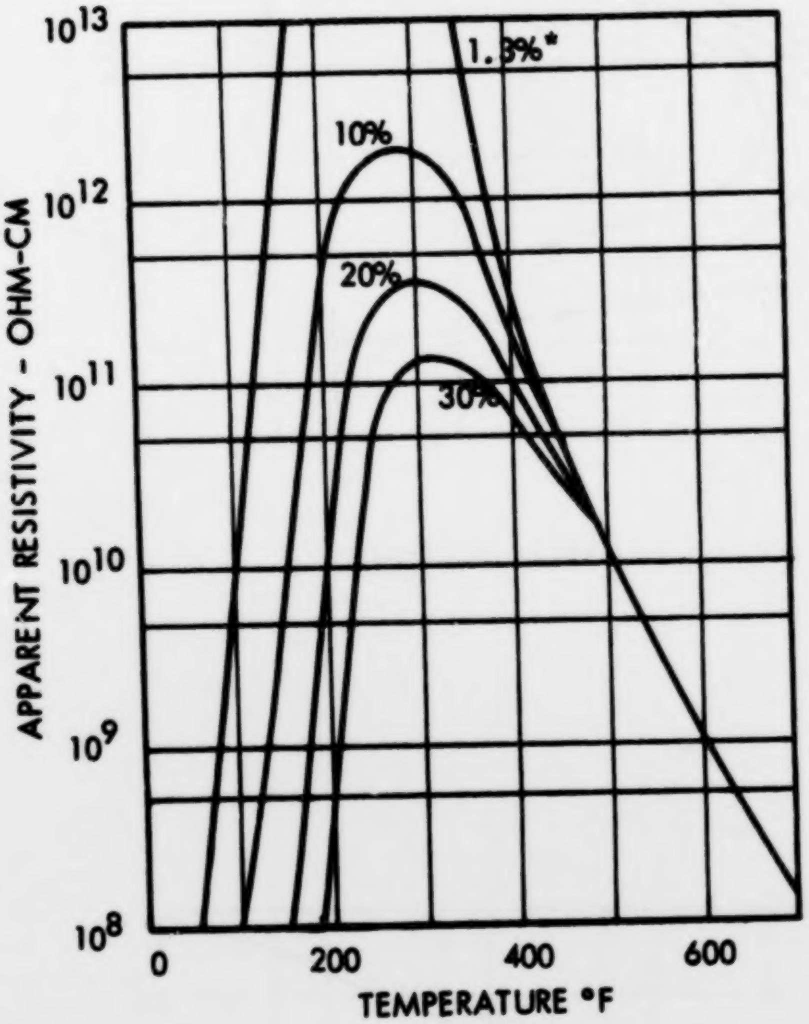
* Figure shows percent water vapor by volume.

Figure 13-4 - Resitivity of Lead Dross Fume Under Varying Conditions of Temperature and Moisture in Gas 18/



* Figure shows percent water vapor by volume.

Figure 13-5 - Apparent Resistivity of Lead Fume from Lead Blast Furnace 16/



* Figure shows percent water vapor by volume.

Figure 13-6 - Apparent Resistivity of Lead Fume from Slag Treatment Plant[16]

TABLE 13-3

COMPOUNDS FOUND IN ALUMINUM REDUCTION CELL EXHAUST STREAMS[12]

Category	Chemical Compound	Chemical Formula
1. Fluorides	Sodium fluoride	NaF
Particulate form	Aluminum fluoride	AlF_3
	Calcium fluoride	CaF_2
	Fluoroaluminate (Cryolite)	Na_3AlF_6
Gaseous form	Carbon tetrafluoride	CF_4[a]
	Hydrogen fluoride	HF
	Silicon tetrafluoride	SiF_4
	Hexafluoroethane	C_2F_6
2. Other particulates (Nonfluoride)	Carbon	C
	Aluminum oxide	Al_2O_3
3. Other gases	Carbon monoxide	CO[a]
	Hydrogen sulfide	H_2S
	Hydrocarbons	[b]

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[a] Especially during periods of anode effects.

[b] Too numerous to mention; type and quantity will depend upon cell employed.

TABLE 13-4

ATMOSPHERIC POLLUTANTS FROM SECONDARY SOURCES[a] IN ALUMINUM PLANTS[12]

Source	Atmospheric Pollutants	
	Gaseous	Particulate
Raw materials handling		
Alumina unloading and transfer	--	Al_2O_3
Cryolite unloading and transfer, grinding	--	Na_2AlF_6, AlF_3
Pot lining operation		
Anthracite coal grinding and transfer	--	Coal dust
Coal and pitch mixing	hydrocarbons	
Anode preparation (prebake plants, only)		
Coke unloading, transfer and grinding	--	Coke dust
Pitch unloading and transfer	--	Pitch dust
Mixing of coke and pitch	hydrocarbons	
Anode baking furnaces	SO_2, CO, hydrocarbons, AF	Carbon dust, particulate
Cleaning of baked anodes	--	Coke dust
Cleaning of copper rods and steel stubs	--	Copper and iron
Electric arc cast iron furnace	--	Iron oxide
Paste making (Soderberg plants, only)	hydrocarbons	Carbon dust
Aluminum refining		
Ingot casting furnaces	Cl_2, HCl	$AlCl_3$, Al_2O_3
Chlorine fluxing	--	

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[a] i.e., excluding the pot line and monitor emissions.

The application of control methods for copper smelter operations has been described in a translation of a 1960 German study.[2] Significant parts of this study are included in the following paragraphs. However, it should be noted that German practice does not necessarily correspond to present-day practice in U.S. smelters. Table 13-5 summarizes operating data for dust control equipment reported in Reference 2.

13.2.3.1 Cloth Filters: Cloth filters are utilized for secondary dust collection from converter gases. Depending on the purpose of utilization, the following types of fabrics are employed:

Cloth woven from natural fibers (wood, cotton);
Cloth woven from synthetic fibers (Redon, Pan, etc.)

The dust content of the exhausted air is strongly influenced by the air-to-cloth ratio (ft^3 of raw gas per ft^2 of filter surface) as well as by the structure and density of the filter weave. In order to maintain the full nominal rating of the filter in continuous operation, cleaning of the filter cloth is of the greatest importance.

The disadvantage of all cloth filters is the high wear and expensive replacement, the high cost of maintenance and the high consumption of energy due to the pressure drop of 2-5 in. w.g. However, with filters properly maintained, efficiencies up to 99.9% can be attained.

13.2.3.2 Centrifugal Separators: Centrifugal separators installed on furnaces generally have maximum efficiencies of 80-85% and are therefore usually employed for primary removal of coarse dust.[2]

13.2.3.3 Electrostatic Precipitators: Electrostatic precipitators, usually preceded by mechanical collectors, are near-universally applied to the control of particulates from copper smelting. The equipment is normally more massive and rugged than counterparts in the power or other industries, and dust-handling techniques are far more positive. In the 50,000 to 2,000,000 cfm flow ranges under consideration, installed costs for combined mechanical collector-electrostatic precipitators would be $6.00 to $3.00, respectively. Mechanical collectors are typically of the large-diameter (24 in. or more) multicyclone type.

Mild-steel construction is accommodated by maintaining sufficient gas temperatures to preclude corrosion, with temperatures ranging from 300 to 650°F on converters and from 600 to 900°F on roasters. Actual collection efficiency usually is reported in the 98.5 to 99.5% range.[20]

TABLE 13-5

OPERATION DATA FOR DUST COLLECTORS APPLIED TO PRIMARY COPPER SMELTING AND REFINING[a]

Type of Separator	Maximum Efficiency* (%)	Draft Required in. water	Utilization
1. Dust chambers	30-60	< 0.2 3-6	Beyond sintering machine and shaft furnace
2. Cyclones ≤ 16 in. in diameter	85-95	3-4	For secondary purification beyond reverberatory furnaces
3. Electrostatic precipitators	96-99	0.2-0.6	For higher demands and fine dust beyond roasting, sintering and shaft furnaces
4. Cloth filters	99%+	2-6	For dry air beyond coolers for converter gas. Efficiency depends on weave

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[a] Largely dependent on type of dust, content of dust, particle-size distribution, gas and operating factors.

13.3 PRIMARY LEAD SMELTING AND REFINING

All primary lead smelters in this country use essentially the same processing steps, although there are differences in the equipment used and the details of operation. The principal process steps are sintering, reduction in a blast furnace, and refining. Refining includes operation of the dross reverberatory furnace. Smelter operations usually include cadmium recovery and slag fuming for zinc recovery.

Lead sulfides are converted to oxides of lead and sulfur in the sintering step at a relatively low temperature. The oxidized solid material is then reduced with coke in the blast furnace at a high temperature to form impure metal and slag. A preliminary refining operation is performed on the impure lead from the blast furnace. Lead bullion, 95 to 99% pure, is the principal product of lead smelting operations.

There are a number of secondary products. Some, such as zinc oxide products and cadmium dusts, may be ready for marketing as they leave the plant, and some, such as slag, matte, or dusts, may be shipped to other plants for extraction of values, primarily zinc, cadmium, silver, and copper. These other products vary from plant to plant, as one plant may put out several finished products, while another may ship only lead and unrefined materials.

Figure 13-7 shows the overall process of the operation.

13.3.1 Emission Sources and Rates from Primary Lead Smelting and Refining

13.3.1.1 Sintering Machines: Sintering is a universal practice in the lead-smelting industry. Its purpose is to remove sulfur by roasting and at the same time sinter to produce a calcine that is consolidated in a strong and porous mass suitable for reduction in a blast furnace. The main chemical reactions taking place on the sintering machine are the oxidation of lead and other metal sulfides with oxygen.

Sintering machines are continuous conveyors made of grate-bar pallets joined together. They are known as Dwight-Lloyd machines. Most of the older and smaller machines are of the downdraft type. A sectionalized windbox installed beneath the pallet line is used to regulate the burning rates in the machine. Newer installations usually have a single large updraft machine with the windbox located above the pallets. Emission points include the windbox and discharge points.

Sulfur dioxide concentration in the sinter machine off gas may be 0.8 to 1.8% by volume. Gas volumes run 100 to 220 scfm/sq ft of bed

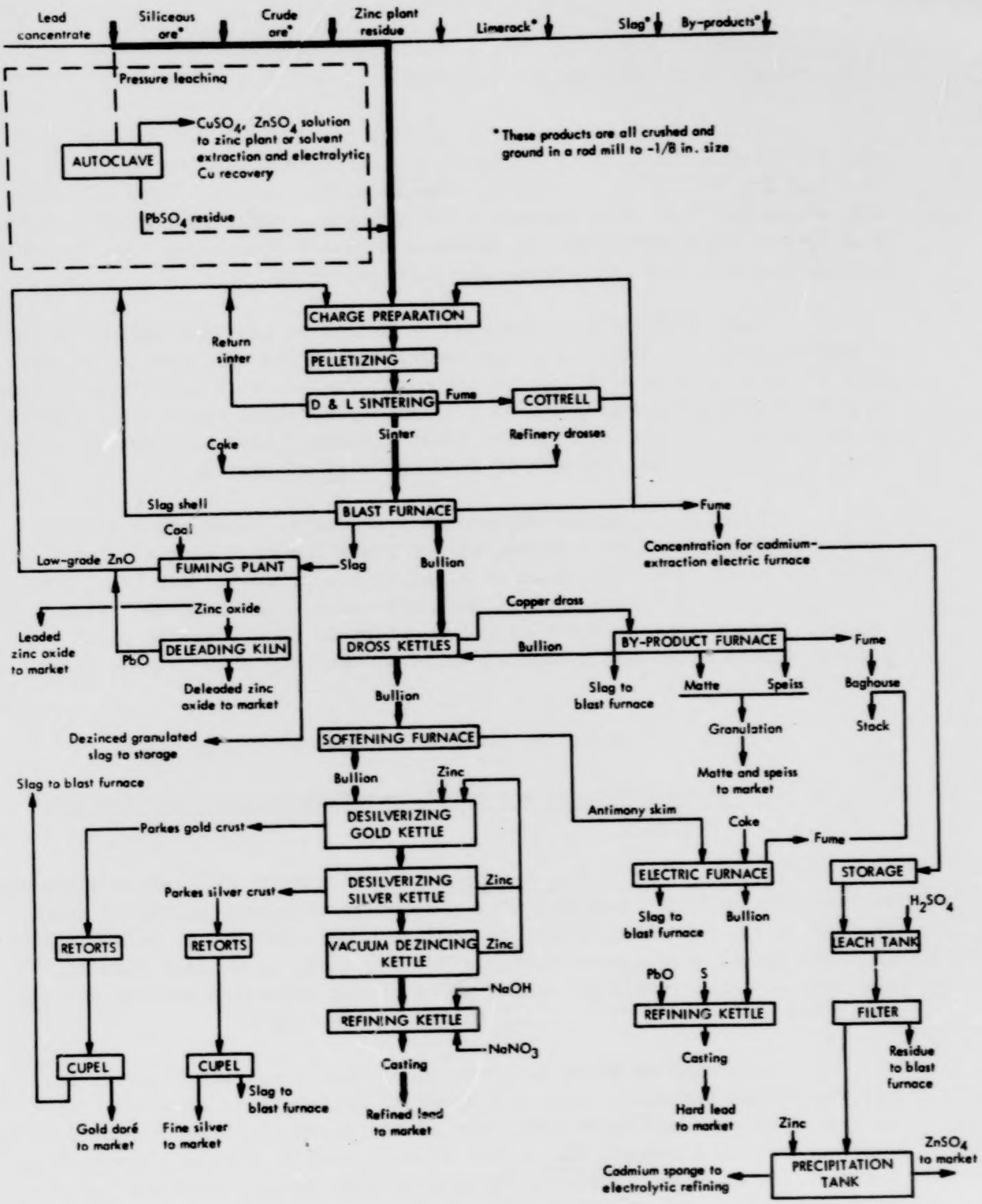

Figure 13-7 - Typical Flowsheet of Pyrometallurgical Lead Smelting 19/

area. When the off gas is to be fed to a sulfuric acid unit, the machine is operated to produce a smaller volume of gas with 4 to 6% or more of sulfur dioxide. The dust and fume load carried by the gas is usually from 5 to 20% of the feed to the machine.[1]

13.3.1.2 Blast Furnace: The purpose of the blast furnace is to reduce the lead oxide in the sinter to metallic lead. The reducing agent is carbon monoxide derived from coke fed into the furnace. Dilution of the flue gas at the top of the furnace is necessary, since without it the gas would have a temperature near 1100° to 1300°F and contain 25 to 50% carbon monoxide. The dilution air burns the carbon monoxide to carbon dioxide, but the volume is large enough to also cool the gas.[1]

13.3.1.3 Lead Refining: The lead-refining process in a primary smelter consists of the dross reverberatory furnace and lead refining kettles. The product is lead bullion. The dross reverberatory produces also matte and speiss, which are shipped to a copper smelter for recovery of the large percentage of copper they contain.

The dross furnace usually operates only 50 to 70% of the time the refinery operates. A very small amount of sulfur oxide is emitted. Matte and speiss both contain sulfur, but most of this remains in the material that is shipped from the lead plant. A layer of dross on the hot material in the furnace permits oxidation of only a small portion of the sulfur. Particulates emitted from these operations would be principally metallic fumes.[1]

13.3.1.4 Other Smelter Operations: Some lead smelters operate such other equipment as cadmium roasters, slag fuming furnaces, and deleading kilns. The slag furnace recovers zinc oxide from blast furnace slag.

13.3.1.5 Summary of Emission Rates: Table 13-1 summarizes the emission rates from the various processes involved in the production of primary lead. Limited emission data were found for various processes in primary lead production, and the totals in Table 13-1 are considered as conservative estimates.

13.3.2 Characteristics of Effluents from Primary Lead Production

The chemical and physical properties of effluents from primary lead smelters are summarized in Table 13-2. Particulate emissions from primary lead production are similar in character to those from copper processing. The metallic fumes are submicron size, difficult to wet, readily agglomerate, cohesive, and will bridge and arch in hoppers.

A typical sample of lead blast furnace dust contains many different kinds of particles, including a range of lead oxides, quartz, limestone, iron pyrites, iron-lime-silicate slag, arsenic compounds and a host of other compounds containing metals associated with lead ores. The major constituents are (1) light red-orange to red fragments of litharge; (2) yellow, rounded particles of massicot; (3) red birefringent, fragments of Pb_3O_4. Also present are a variety of vitreous iron-lime-silicate slag particles; these can have almost any color (yellow, green to brown).

13.3.3 Control Practices and Equipment for Lead Smelting and Refining

The sulfur content of lead concentrates is reduced by sintering them on Dwight-Lloyd sintering machines. Dust and fume are recovered from the sinter machine gas stream by settling in large flues and electrostatic precipitators or baghouses.5/ Collection efficiencies are up to 96% for precipitators and 99.5% for baghouses.5/

Blast furnace gases, after cooling, may be cleaned in baghouses using wool or fiberglass bags. The collected dust from the blast-furnace operation contains up to 65% lead and usually appreciable quantities of cadmium and arsenic. Therefore, it is recycled back to the sintering machine. Lead refineries also have baghouses for recovery of fume from softening furnaces and cupeling furnaces.5/

The processes and control methods for lead smelter operations have been described in a translation of a 1961 German study.6/ Table 13-6 summarizes some of the more pertinent data from this study. However, German practice may not correspond to current practice in U.S. smelters.

TABLE 13-6

LEAD SMELTER CONTROL EQUIPMENT6/

	Control Device		Efficiency	
Process	Primary	Secondary	Primary	Secondary
Sinter Machine	Centrifugal	Electrostatic precipitator, bag filter	80-90	95-99
Blast Furnace	Centrifugal	Electrostatic precipitator	80-90	95-99
Reverberatory Furnace	Waste heat boilers, tubular coolers	Electrostatic precipitator, bag filter	70-80	95-99

13.4 PRIMARY ZINC SMELTING

Since practically all zinc ores as mined are too low in zinc content for direct reduction processes, they must first be concentrated. After concentration, the first step in the extractive metallurgy of zinc is virtually always roasting the concentrate. If the roasted concentrate, or calcine, is to be subjected to high-temperature reduction with carbon, it is usually first sintered in order to minimize dusting loss, volatilize impurities, and permit better circulation of reducing gases around the sintered particles. If the calcine is to be reduced electrolytically, it is dissolved directly in the spent electrolyte, consisting primarily of dilute sulfuric acid, just returned from the electrolytic cells.

Figure 13-8 illustrates a simplified flow diagram for a zinc smelter.

13.4.1 Emission Sources and Rates from Primary Zinc Smelting

13.4.1.1 Zinc Ore Roasting: Zinc sulfide concentrates are usually converted to zinc oxide calcines by a roasting process. There are 12 plants in the United States roasting sulfide concentrates.[1] Two of these use the old Ropp roasters, which produce a roaster gas too low in sulfur dioxide for recovery by an acid plant. One plant uses multiple-hearth roasters that produce a much-diluted waste gas with < 1% sulfur dioxide, also too low for recovery by an acid plant. Nine plants recover a large part of the sulfur with acid plants. One of these uses multiple-hearth furnaces only for the first stage of a two-stage roasting process. Roasting capacity in the remaining plants is about equally divided between fluid bed and suspension roasters.

Operating conditions for zinc-sulfide concentrates vary from plant to plant according to the composition of the raw material and the specific use of the roaster calcine. Higher roasting temperatures (1800°F and over) eliminate more cadmium, and increase the formation of ferrites. Excess oxidizing air results in lower temperatures and good sulfur elimination, but also lowers the sulfur dioxide concentration in the roaster gas.[1]

Depending on the type of furnace, the gases escaping from the furnace contain greater or lesser amounts of dust of different composition and grain size. Table 13-7 lists several types of roasters and some operating conditions.

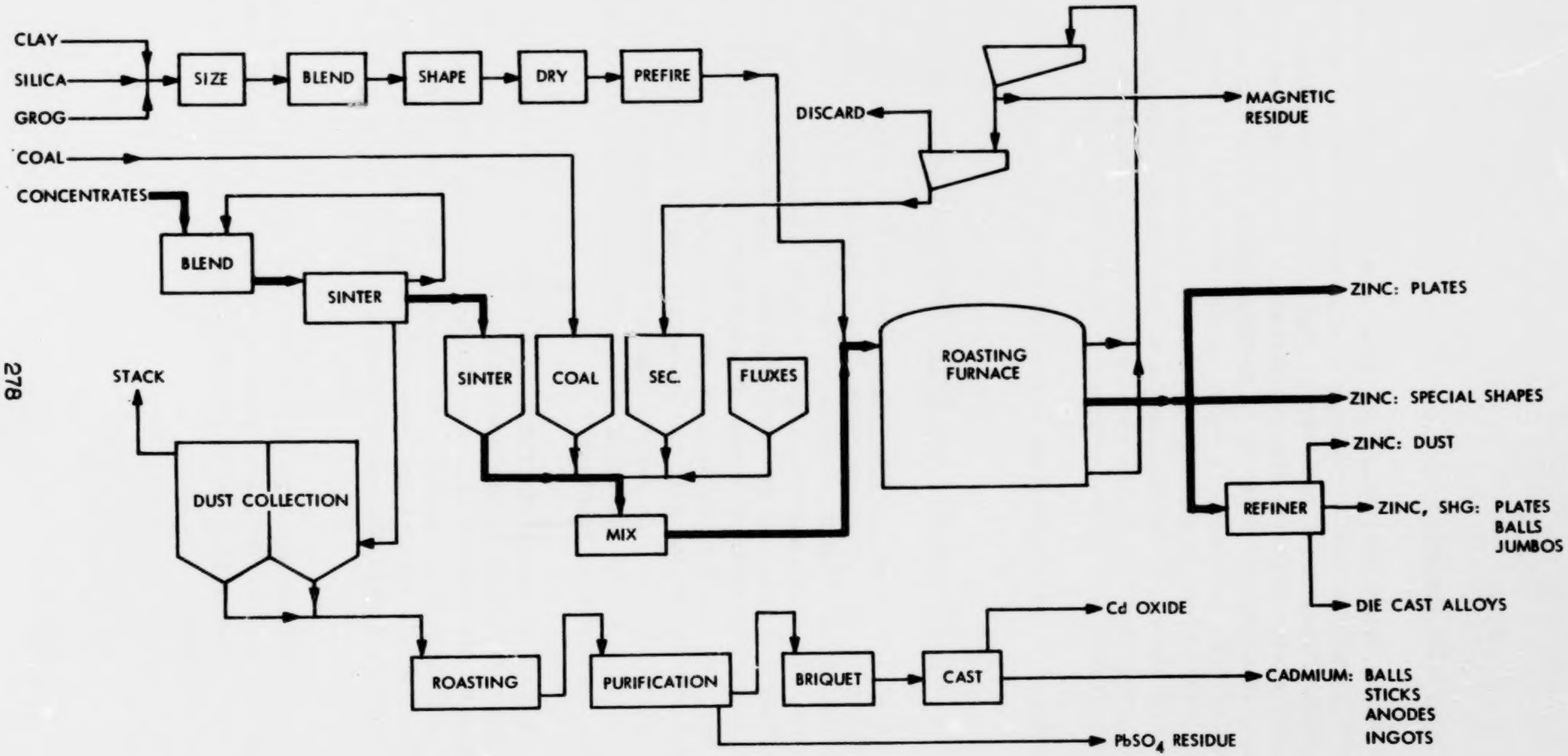

Figure 13-8 - Zinc Smelting Flow Diagram

TABLE 13-7

TYPICAL ZINC ROASTING OPERATIONS[a/][1/]

Type of Roaster	Operating Temp. (°F)	Feed Capacity (tons/day)	Dust in Off Gas Percent of Feed
Multihearth	1,200-1,350	50-120	5-15
Multihearth[b/]	1,600-1,650	250	5-15
Ropp[c/]	1,200	40-50	5
Fluid-bed[d/]			
Dorr-Oliver	1,640	140-225	70-80
Fluid-bed[b/]			
Dorr-Oliver	1,650	240-350	75-85
Fluid-bed			
Lurgi	1,700	240	50
Suspension	1,800	120-350	50
Fluid-column	1,900	225	17-18

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a/ Dead roast except where noted otherwise.

b/ First stage is a partial roast in multihearth, second stage is a dry-feed dead roast in Dorr-Oliver fluid bed.

c/ Partial roast.

d/ Slurry feed.

13.4.1.2 Sintering: Sintering in the zinc industry is used mainly to agglomerate the roaster calcine for subsequent processing. The process is sometimes used with only raw sulfide concentrates or a mixture of calcine and raw concentrates as feed.

Sintering machines have continuous conveyors made of grate-bar pallets, upon which the feed material is placed and processed. Downdraft machines are universally used in the zinc industry. The downdraft is produced by sectionalized wind boxes installed beneath the line of travel of the pallets. This construction permits draft regulation in separate areas of the grate. The gases may be recirculated from one end of the machine to the other.[1/]

With air at three to five times the theoretical amount to burn the coke and residual sulfur, the temperature of the combined exit gas ranges from 500° to 700°F. Sinter exit gas is further cooled by air dilution and water sprays to condition it for cleaning in dust collectors.

13.4.1.3 Calcining: Calcining is a heat-treating process that is used for oxidized materials, e.g., oxide ore concentrates; material from roasting of sulfide ore concentrates. It may be called nodulizing, since hard nodules of random sizes are produced when the calcining is done in a rotary kiln. The nodulized kiln product is subsequently treated for zinc extraction. Sulfur oxides are evolved only when roaster calcine that contains small amounts of sulfur is being processed, and in such cases the waste gas from the kiln may have from 0.1 to 0.2% sulfur dioxide. The waste gas also contains some fume, which is removed in bag filters and treated for recovery of lead and cadmium.[1]

13.4.1.4 Metal Extraction: Roasting, sintering, and calcining are preliminary steps to one of the extraction methods: pyroreduction or leaching and electrolysis. Pyroreduction distillation or retorting of the sinter or calcine is performed in horizontal or vertical retorts, electrothermal open or submerged arc furnaces, or blast furnaces. Horizontal retorts are small ceramic cylinders that are mounted horizontally in racks that hold several rows of retorts mounted one over the other. They are fed with coal and sinter and produce liquid zinc metal, as do the larger and more modern vertical retorts. Vertical retorts make a by-product carbon monoxide gas that is used as fuel in other parts of the plant. Particulate emitted is zinc-oxide fume.

Zinc fuming can be either an extraction or a pre-extraction operation. In this step, zinc is reduced to metal by carbon or carbon monoxide, vaporized, and reoxidized to form a zinc-oxide fume which is collected in bag filters. The zinc oxide collected may be fairly pure, in which case it is a final product. If it contains appreciable quantities of lead and cadmium it is usually treated further.[1]

13.4.1.5 Summary of Emission Rates: Table 13-1 summarizes the emission rates from the various processes involved in the production of primary zinc. The roasting operations produce about 40% of the particulate emissions, while ore crushing and materials handling account for nearly 45% of the total.

13.4.2 Characteristics of Effluents from Primary Zinc Production

The chemical and physical properties of effluents from primary zinc smelters are summarized in Table 13-2. Particulate emissions comprise metallic fumes from furnace and coarse dust from mechanical processes. The metallic fumes are difficult to wet, readily agglomerate, and will bridge and arch in collector bins.

13.4.3 Control Practices and Equipment for Zinc Smelting and Refining

For efficient recovery of zinc, the sulfur content of the concentrate is reduced to 2% by roasting. Multiple-hearth or Ropp roasting may be followed by sintering, or double-pass sintering may be used alone. Sintering in zinc smelters produces SO_2 which is converted into sulfuric acid by the contact process. The sinter plant gases can be precleaned by electrostatic precipitator, baghouses, or wet scrubbers.[7] The collection of sintering fume involves a large volume of gases in the range of 1,300,000 scf/ton of zinc product. Zinc smelter sintering fume is difficult to collect efficiently by electrical means because of its inherently high electrical resistivity. This requires close control of gas temperature and moisture content to maintain efficient collection.[8] Horizontal-flow, plate-type precipitators have been installed on most of the newer zinc sintering machines. Moisture and/or steam is normally added to improve dust resistivity for optimum precipitation. Mild-steel construction is common, and installed costs for base collectors of 50,000 cfm would be \$3.50/cfm.[20]

Fluid-bed roasters have been used to process agglomerated feed. Exhaust gases were cleaned in a waste-heat boiler, cyclones, and an electrostatic precipitator in series. The metallic composition of the dust is a function of roasting temperature, Figure 13-9.[9]

The fume-recovery facilities at a Canadian smelter operation have been described.[10] Data for the facilities are shown in Tables [illegible] and 13-9. These facilities used electrostatic precipitators for controlling the emissions from zinc-roasting and lead-sintering operations. The zinc roaster gases entered the precipitator at 420°F without pretreatment. The lead sintering gases required conditioning in a spray tower.[11] The precipitators were very versatile, but the paramount problem was corrosion caused by condensed vapors. The Doyle scrubber (Table 13-8) operates on the principle of high velocity impingement of the dirty gas into water. Recovery efficiencies were in the range of 98 to 99+%. The installed costs (Table 13-9), are 1957 year costs, but are two to three times higher than general cost figures given in Appendix A. However, the costs in Table 13-9 include gas pretreatment, inlet and outlet flues, and all accessories such as rectifiers, dust conveyors, pumps, liquid cyclones, and instrumentation.

13.5 PRIMARY ALUMINUM PRODUCTION

Aluminum is produced by the electrolysis of alumina (Al_2O_3) in fused cryolite (AlF_3 - 3 NaF). Essentially all the alumina used is extracted from bauxite. Alumina recovery from bauxite consists of separating the alumina from the various impurities of bauxite, a process

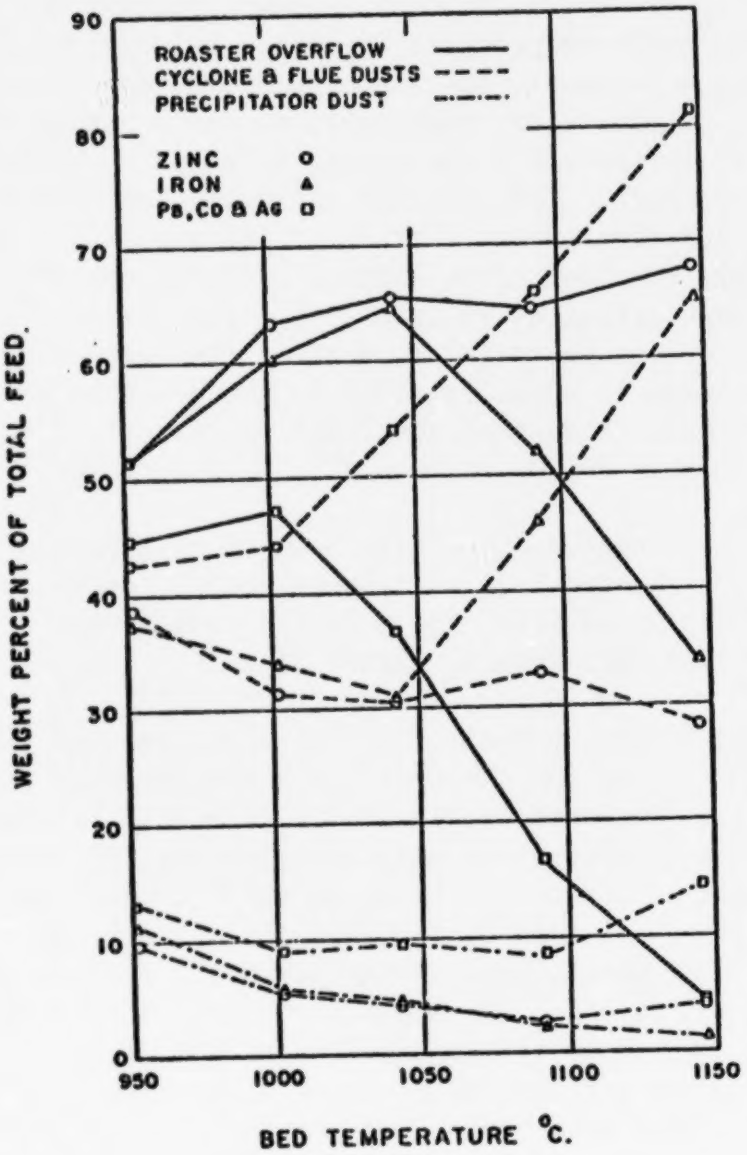

Figure 13-9 - Dust Composition vs. Roasting Temperature in Zinc Processing[9]

TABLE 13-8

COMINCO FUME AND DUST RECOVERY PLANTS[10/]

	Gas Conditions									Dust Conditions		Plant Performance			
	Outlet			Inlet											
Type of Equipment	Volume at NTP	Temp. (°F)	Volume at Temp.	Temp. (°F)	Percent Air Leak	Volume at Temp.	Volume at NTP	Dew Point (°F)	Significant Gas Component (%)	Load Mg/Cu Ft[d/]	Predominant Size Microns	Pressure Drop w.g.	Calculated Gas H.P./ 1,000 CFM[b/]	Other H.P./ 1,000 CFM	Percent Efficiency
Baghouses															
Lead Blast Furnaces	195,000	200	278,000	225	10	262,000	177,000	95	SO_2 0.07 CO_2 4.5	195	< 2	6.0	1.7	1.5	99.8
Slag Fuming	146,000	210	210,000	250	15	193,000	127,000	95	SO_2 0.09 CO_2 6.0	268	< 2	6.0	1.7	1.1	99.7
Silver Refinery No. 1	7,400	118	9,200	155	12	8,700	6,600	45	CO_2 3.0 O_2 15	26	< 1	2.0	0.6	1.8	99.9
Silver Refinery No. 2	9,200	180	12,700	200	12	11,700	8,200	80	CO_2 3.0 O_2 15	220	< 1	2.0	0.6	0.6	99.6
Antimonial Lead Plant	6,100	174	8,310	195	12	7,660	5,450	110	--	5.2	< 1	4.5	1.3	2.2	97.5
Coal Crushing	12,300	90	14,550	110	10	13,700	11,200	45	--	194	20	3.0	0.9	0.5	95.0
Calcine Elevator (Zinc Roasters)	7,400	85	8,675	100	12	7,960	6,600	32	--	97	+ 20	3.0	0.9	0.3	98.0
Pilot Plant	5,600	180	7,710	200	15	6,900	4,860	85	CO_2 5.0	165	< 10	2.5	0.8	0.3	96.5
Electrostatic Precipitators															
Lead Sintering No. 3[a/]	140,000	135	180,000	150	15	160,000	122,000	130	SO_2 2.0	130	< 1	0.10	0.03	1.4	97.0
Zinc Roasting No. 9[a/]	86,000	390	157,000	420	10	147,000	78,000	150	SO_2 6.5	210	5	0.08	0.02	1.3	90.0
Cyclones															
Coal Drying	9,500	100	11,400	110	5	11,000	9,000	95	CO_2 2.0	800	50	3.0	0.9	0.3	91.0
Zinc Roasters	78,000	650	186,500	730	5	190,000	74,200	170	SO_2 7.5	1,000	20	6.5	1.9	0.4	87.5
Pilot Plant Kiln	1,200	630	2,820	690	5	2,830	1,140	--	CO_2 1.5	220	10	5.0	1.4	--	75.0
Doyle Wet Scrubbers															
Sinter Plant Dryers	67,000	177	92,000	275	Nil	105,000	67,000	167	SO_2-0.07	250	40	8.0	2.3	0.5	97.0
Sinter Plant Ventilation	158,000	72	180,000	88	Nil	186,000	158,000	76	--	100	15	8.0	2.3	0.7	99.0
Refinery Melting Kettle	5,700	118	7,090	142	Nil	7,400	5,700	130	--	22	5	9.2	2.6	2.1	96.2
Zinc Sulphide Pachucas	4,420	82	5,160	90	Nil	5,250	4,420	74	--	100	20	8.0	2.3	--	95.7
Coal Dryers	10,800	82	12,600	100	Nil	13,000	10,800	93	CO_2 2.0	65	10	8.5	2.4	--	95.0
Pilot Plant Kiln	1,610	80	1,860	194	Nil	2,260	1,610	--	CO_2 1.5	800	10	9.1	2.6	--	96.4

TABLE 13-8 (Concluded)

	Treatment Plant									
Type of Equipment	No. of Units	Components/ Unit	Bags/ Component	Total No. of Bags	Bag Diameter (in.)	Bag Length (ft.)	Total Sq. Ft. Cloth	Ratio[c]	Cleaning Cycle (min.)	Fabric
Baghouses										
Lead Blast Furnaces	20	1	396	7,920	5	10½	107,700	2.4	15	Orlon
Slag Fuming	16	10	18	2,880	5	10	54,000	3.5	8	Orlon
Silver Refinery No. 1	2	4	25	200	5	10	3,750	2.3	2	Wool
Silver Refinery No. 2	2	8	25	400	5	10	7,500	1.6	2	Orlon
Antimonial Lead Plant	4	1	25	100	3	10	1,875	4.1	15	Orlon
Coal Crushing	3	1	144	432	5	10½	5,920	2.3	15	Cotton
Calcine Elevator (Zinc Roasters)	3	1	120	360	5	10½	4,860	1.6	15	Cotton
Pilot Plant	3	1	120	360	5	9½	4,320	1.6	15	Orlon

Cottrells	No. of Units	Seconds/ Unit	Gas Velocity (ft/sec)	Continuing Time (sec.)	Wires	Plates	Voltage	Material of Construction
Lead Sintering No. 3[a]	5	4	4.6	8.5	Iron	Aluminum	60,000	8 in. Brick wall, brick-lined dust hoppers, wooden decking.
Zinc Roasting No. 9[a]	4	2	4.0	5.0	Iron	Iron	60,000	Brick construction with sand seals

Cyclones	No. of Units	Material of Construction
Coal Drying	2	Mild steel
Zinc Roasters	15	Mild steel
Pilot Plant Kiln	1	Mild steel

Doyle Wet Scrubbers	No. of Units	CFM/ Unit	Material of Construction	Total Water Flow GPM	pH of Effluent Counterflow	I/G Ratio	Nozzle Velocity (ft/sec)
Sinter Plant Dryers	3	36,000	Lead with 316SS ducts and nozzle	120	3	0.29	150
Sinter Plant Ventilation	30	2,500 to 20,000	Steel and lead	189	4	0.17	150
Refinery Melting Kettle	2	4,000	Mild steel, neoprene lined	6	2 to 3	0.13	155
Zinc Sulphide Pachucas	1	5,000	Wood with lead duct and nozzle	6	4	0.17	150
Coal Dryers	1	12,000	Mild steel	12	6	0.15	152
Pilot Plant Kiln	1	2,000	316 Stainless steel	3	3	0.24	160

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a/ Gas then to absorption plants for further cleaning and SO_2 recovery.

b/ At 55% efficiency.

c/ Inlet volume at temperature divided by square feet of cloth.

d/ Inlet volume at temperature.

TABLE 13-9

COSTS FOR CLEANING METALLURGICAL GASES (1957 DATA[10])

	Plant	Inlet		Installed Cost	Operating and Maintenance	Cost Items Included			
		CFM	°F	$/ACFM	¢/1,000 Cu. Ft.	No. of Fans	Pretreatment	Building	Tons of Dust/ Day
1.	Blast furnace baghouse	262,000	225	4.35	0.19	4	Cooling	Yes	70
2.	Slag fuming baghouse	193,000	250	4.80	0.26	3	Cooling	Yes	250
3.	Sintering electrostatic precipitator	160,000	150	5.10	0.22	1	Humidifying	Yes	15
4.	Zinc roaster electrostatic precipitator	147,000	420	4.65	0.13	1	Nil	Yes	50
5.	Four tadanac dryer cyclones	38,800	300	1.93		2	Nil	No	
6.	Sinter dryer scrubbers	106,000	275	1.90		3	Nil	No	
7.	Sinter ventilation scrubber	3,000	100	2.23		1	Nil	No	
8.	All sinter scrubbers	292,000			0.07	20	Nil	No	20

accomplished by chemical means. For this purpose, advantage is taken of the amphoteric properties of the aluminum ion, which permit the metal to be solubilized in the form of an alkaline aluminate, particularly the form of sodium aluminate.

The Bayer process, shown in Figure 13-10, is used in most cases to recover the alumina. As shown in Figure 13-10, following separation and washing hydrated alumina is fed to large rotary furnaces, similar to cement kilns, wherein the alumina is calcined at about 1200°C. This operation is necessary not only for the purpose of eliminating the 45% of water (including the 30% combined water present in the hydrated material), but also for giving some of the alumina the crystalline α (or corundum) form, which is most advantageous for electrolysis. These furnaces or kilns are significant sources of particulate emissions. The calcined alumina for aluminum production obtained from these kilns is in the form of a white powder consisting of aggregates which range in size up to about 100 μ, and which are made up of monocrystals of anhydrous alumina at various stages of crystallization.

The alumina is next sent to a primary aluminum processing plant where the alumina is converted to the metal by electrolysis. The heart of the operation is the electrolytic cell where direct current dissociates alumina into oxygen and molten aluminum metal. These cells are called "pots" and are arranged to form potlines having several hundred cells per potline. Each cell requires 40,000 to 100,000 amp. of current under normal operating conditions. As shown in Figure 13-11 (prebaked anode cell), the molten aluminum collects at the bottom of the bath above a carbon lining which acts as the cathode. Oxygen migrates to the carbon anode, forming carbon dioxide or carbon monoxide at high cell temperatures which usually reach 940°C.

Periodically aluminum metal is withdrawn, and fresh alumina feed and bath chemicals added by piercing the frozen crust of the bath. Crust-breaking agitates the bath and is a time of increased particulate and gaseous emissions. Thermal buoyancy of heated air plays a large part in sweeping finely divided alumina and bath fumes out of the cell. Ducts over the cells capture some of the escaping fumes, but some elude capture and are emitted into the building atmosphere and find their way to the atmosphere through roof ventilators or "monitors," also shown in Figure 13-11.

While all aluminum production employs the basic Hall-Heroult process, several variations in cell construction have evolved, based upon the method of anode manufacture. It is important to understand the differences in cell construction because the type of cell employed will affect the types and quantities of pollution generated. The types of cells are: (1) the prebake cell; (2) the horizontal stud Soderberg cell; (3) the vertical stud Soderberg cell. Figures 14-12, 13 and 14 illustrate the various cells.

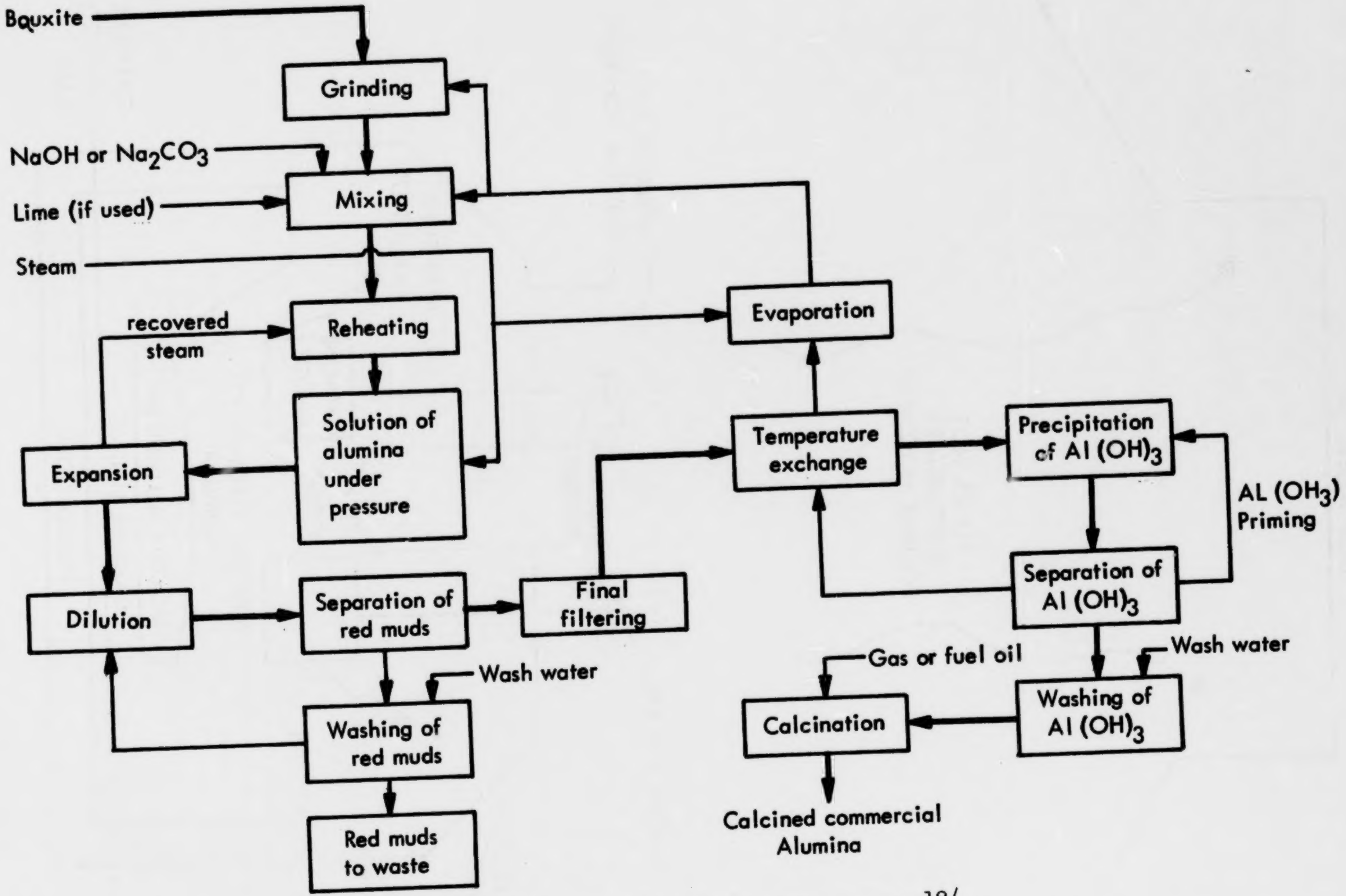

Figure 13-10 - Diagram of the Bayer Process[19/]

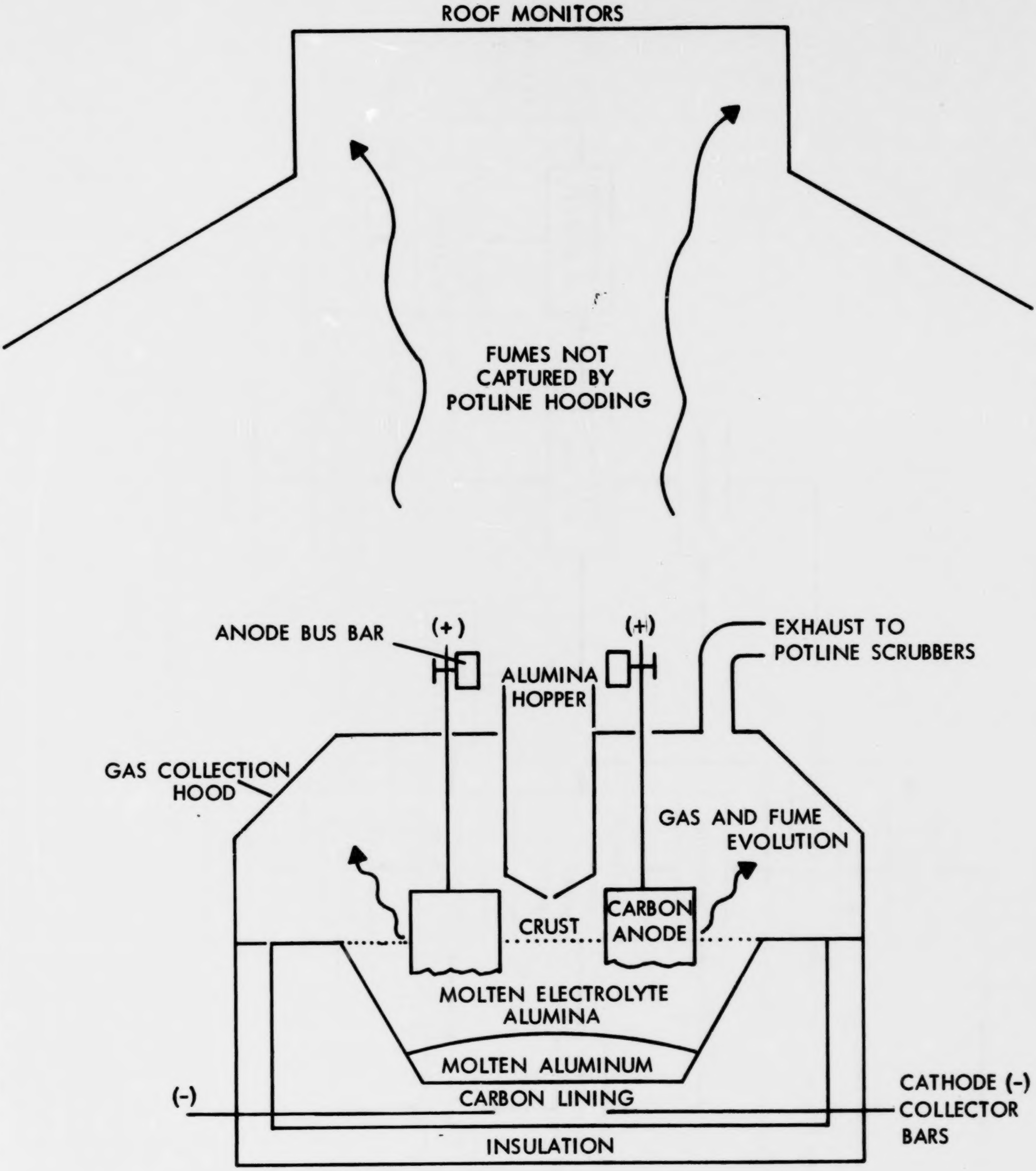

Figure 13-11 - Aluminum Cell (Prebaked Anode Type)[12]

ALUMINUM REDUCTION CELLS

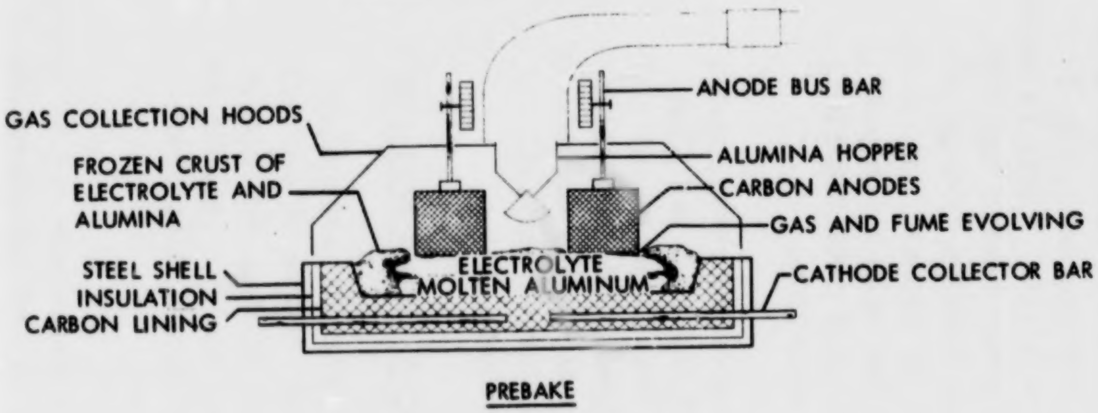

Figure 13-12 - Prebake

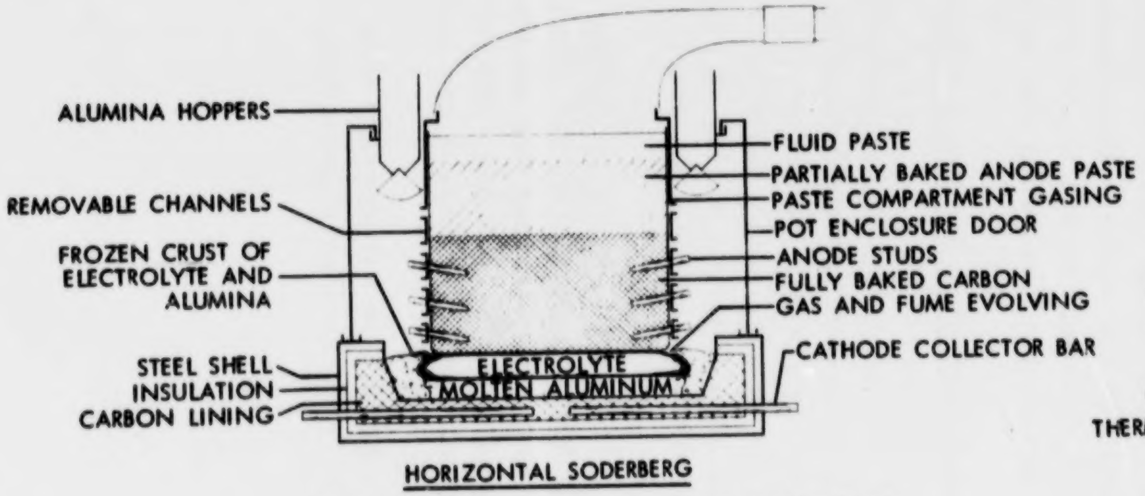

Figure 13-13 - Horizontal Soderberg

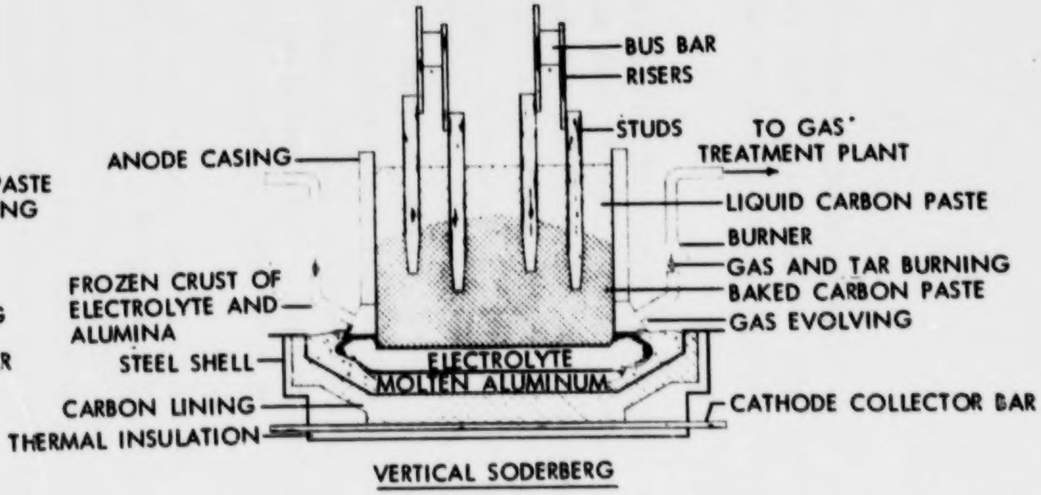

Figure 13-14 - Vertical Soderberg

In a prebake anode plant, pitch and coke are mixed, pressed and baked before use in the cell. The carbon anodes are rectangular in cross section and supported by copper or aluminum hangers to the electrical busbars overhead.

The other types of cells bake anodes at the cell itself by introducing a carbon paste directly and using the heat of the melt to form the carbon anode. Prebaking of the anode is therefore avoided, and continuous operation of the cell is possible. Known as the Soderberg cell, one type, the vertical stud Soderberg cell, is shown in Figure 13-14. Paste is added to the top of the cell and slowly carbonized as it moves toward the bath. Metal studs carry electric current to the carbonized portion through the top, and are positioned vertically with respect to the anode: hence, its name. Cell construction allows gases liberated by the cell to be easily collected and burned. Both vertical stud and horizontal stud Soderberg exhausts are rich in hydrocarbons from the baking operation.

Hooding requirements for the horizontal stud Soderberg, shown in Figure 13-13, are much more difficult because of the stud positions along the side of the electrode rather than at the top. Continuous consumption of the anode forces repositioning of the studs and necessitates easy access to the anode. Requirements for easy anode access complicate fume collection and do not allow burning of gas and tar at the cell itself, as is practiced with the vertical stud Soderberg cell.

13.5.1 Emission Sources and Rates from Primary Aluminum Production

Little information is available about amounts of particulate emissions from aluminum production plants. The major source of particulate emissions is the reduction cells, as discussed below. Secondary sources are summarized in Table 13-4.[12/] Secondary sources include raw materials handling, pot lining operations, anode preparation (prebake plants), cleaning operations, and aluminum refining.

13.5.1.1 Reduction Cells: Reduction cell emissions can be divided into roof monitor emissions and the potline control system emissions.[12/] The roof monitor emissions are emitted at the building height along the entire length of the building and may be considered a line source. Potline control system emissions are emitted from stacks.[12/]

Actual emissions vary widely from plant to plant, depending upon age, cell type, operating procedure, and efficiency of the hoods over the cells.

13.5.1.2 Anode Furnace: The anode furnace is a source of fluoride, sulfur dioxide, and particulates in prebake plants. Sulfur dioxide emissions will depend upon the sulfur content in the pitch and the coke of the anode.

13.5.1.3 Casting Furnace: Aluminum casting furnaces also emit particulate pollutants. In the casting furnace aluminum from the primary cells is refined by heating and by chlorination. Products of the reaction are aluminum chloride, aluminum oxide and heavy metal chlorides liberated from impurities. Free chlorine and hydrochloric acid are likely to be present in the off gas.

13.5.1.4 Summary of Emission Rates: Table 13-1 summarizes the emission rates from the various stages in the production of primary aluminum. Emissions from the reduction cells currently total about 65,000 tons/year.

13.5.2 Characteristics of Effluents from Primary Aluminum Production

The chemical and physical properties of effluents from primary aluminum production are summarized in Table 13-2. Particulates emitted from the refining and casting furnaces range in size down to submicron levels. The particulates are abrasive and corrosive. Fluorides, both gaseous and particulate, are a component of emissions from the reduction cells.

13.5.3 Control Practices and Equipment for Primary Aluminum Production

The control of emissions from the on-site operations of bauxite drying and alumina calcining involve high dust concentrations which frequently dictate the use of multicyclones for preliminary particulate collection, usually followed by electrostatic precipitators. Fabric filtration can be used if close temperature control is practiced. Collection efficiencies of 99.7+% have been reported for such systems.[20/]

Reported process flows of from 25,000 to 250,000 acfm result in small-to-moderate sized installations. Installed costs for combined multicyclone/electrostatic precipitators would range from $4.60/cfm for the lower volumes, through $2.30/cfm for the higher, at 99+% overall collection efficiencies. These costs exclude auxiliaries.[20/]

Control of fluoride and particulates from aluminum cell rooms can be classed as:

(1) Capture of cell effluents by potline hooding,

(2) Subsequent collection of captured pollutants in scrubbers, etc.

(3) Scrubbing of roof "monitor" emissions.

Because the choice of electrolytic cell determines the design of hooding and collectors, controls will be discussed separately for the prebake and Soderberg cells. Most of the following discussion and information is from the report "Air Pollution from the Primary Aluminum Industry" by the Washington State Department of Health.[12]

13.5.3.1 Vertical Stud Soderberg Cell: The vertical stud Soderberg cell captures cell effluents most effectively because placement of the anode studs in a vertical position allows a metal skirt to be fixed to the lower end of the steel anode jacket. The skirt reaches down to the encrusted bath and effectively encloses the fuming bath. Gases are, therefore, drawn off with little dilution by air and are concentrated enough to allow combustion of the tarry hydrocarbons. During burning, hydrocarbons are reportedly reduced from 3 to 0.1% by volume, and most fluoridated carbon compounds converted to hydrofluoric acid. The effective oxidation of tar is a great aid to subsequent collection because tar contamination and plugging of ducts are avoided. After burning, exhaust fumes from each pot are sent to a central header fan and control equipment. One piece of control equipment will commonly treat exhaust fumes from 15 pots.

Control devices used for vertical stud Soderberg cells have included multiclones and spray-type scrubbers. The scrubbers use high pressure sprays to contact countercurrently the gases and particulate. Such a system can remove 95% of the fluorides entering the control system, but no figures for total particulate collection efficiencies are reported. Exhausts may be treated by bag filters coated with lime or alumina, or by electrostatic precipitators, but the residual tar creates a fouling problem in the collection system.

A recent addition to the family of collectors is the sieve plate scrubber shown in Figure 13-15. The device has been put into operation in Norway. A three-plate tower has removed 97% of the hydrogen fluoride, 80% of the solid fluoride particles and 70% of the total particulate in incoming gas streams. Higher absorption efficiencies are possible with the addition of a fourth plate. The design allows self-cleaning of the plates by the use of sprays directed at the underside of each plate where heavy tar and particle deposition occur. High-velocity droplets, impelled by the air flowing through the restriction, are blown against the plate and are forced to the top by the air stream, thereby preventing plugging of the sieves. Particulate collection is by impingement on the plates and the water droplets. The tower produces hydrofluoric acid used as recirculation liquor for the first plate.

Another collection system is shown in Figure 13-16. The system incorporates dry cyclones, an electrostatic precipitator and two scrubbers.

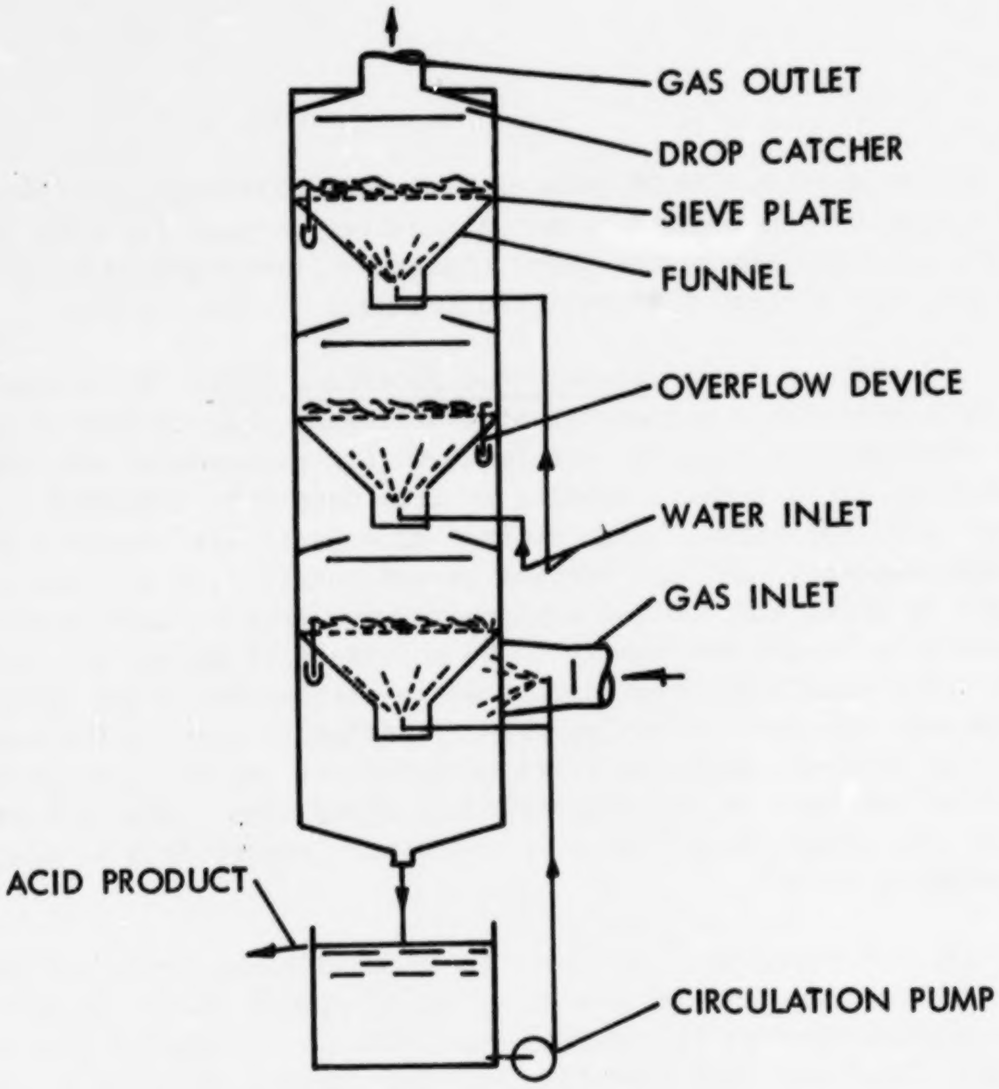

Figure 13-15 - Schematic Drawing of Cross-Sectional View of the New Sieve-Plate Gas Scrubber[12]

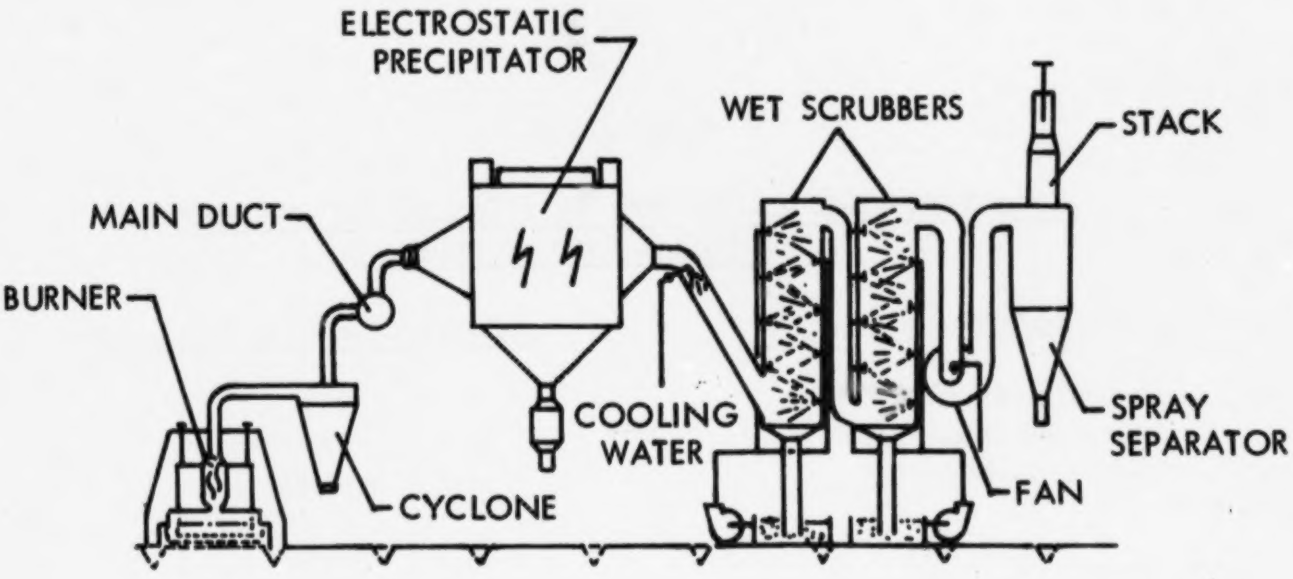

Figure 13-16 - Purification Installation for Cell Gases[12]

The system achieves 99.9% gaseous fluoride collection, but particulate efficiencies were not given. When a scrubber is used for both gaseous and particulate fluorides, the particulates are frequently more difficult to collect, and dictate the power requirements of the scrubber.

13.5.3.2 Horizontal Stud Soderberg Cell: Effective capture of all effluents for a horizontal stud Soderberg cell is much more of a problem, because open channels are required for replacement and readjustment of the studs. As a result, hooding is less complete; therefore, larger volumes of air are entrained. Large volumes of exhaust air create a dilute mixture of hydrocarbons. Because burning is not possible, a tar-fouling problem occurs in ducts and control equipment. Cyclones or multiclones and bag houses have fouled too easily to be an effective answer to control with horizontal stud Soderberg cells. Where electrostatic precipitators are attempted, the plates require water flushing to prevent fouling by tars. Existing controls have consisted of scrubbers, either grid packings in a vertical scrubber or the high-velocity spray type. The lack of primary collectors makes these scrubbers especially susceptible to plugging by particulate matter.

To solve this problem, the Alcan Company developed the floating bed scrubbers whose principle is shown in Figure 13-17. A bed of light polyethylene spheres is shown at rest with no air-liquor flow. The bed becomes fluidized upon operation and the spheres are free to rotate and agitate. Liquor flows down through the interstices, contacting the gases in the air stream, while at the same time washing the spheres. Most importantly, the constant motion of the spheres prevents accumulation of tars on the spheres. Collection efficiencies for the floating bed scrubber are detailed in Table 13-10 for a single bed installation having pressure drops 4 to 6 in.

TABLE 13-10

COLLECTION EFFICIENCIES FOR THE FLOATING BED SCRUBBER
USED ON HORIZONTAL STUD SODERBERG CELL

Substance	Collection Efficiency (%)
Total fluorides	90+
Hydrogen fluorides	98+
Particulates	80-90[a]

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[a] Anticipated efficiency at higher pot ventilation rates of 3,600 scfm and when doors are closed.

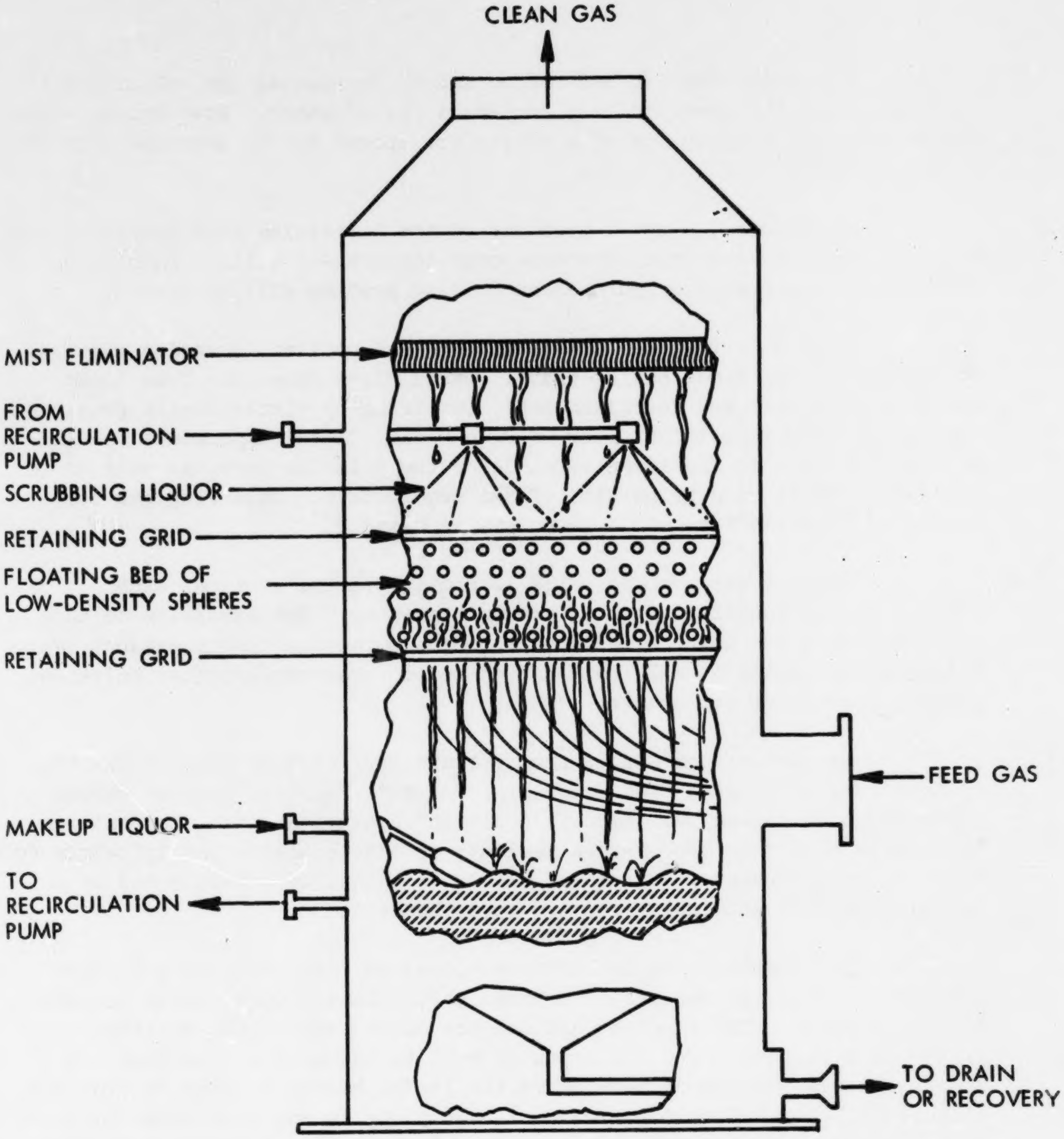

Figure 13-17 - The Floating Bed Scrubber Developed for Horizontal Stud Soderberg Cell Exhausts[12/]

A second floating bed can be added, increasing the collection efficiencies and the pressure drop another 4 in. of water. However, an additional bed will require use of a larger horsepower fan to overcome increased pressure drops.

In summary, control problems of the horizontal stud Soderberg cell have lessened its economic advantage over the prebake cells. Additional research to overcome the hydrocarbon fouling problem will be needed.

13.5.3.3 Prebake Cells: The prebake potline operation requires an on-site carbon-anode baking plant. Particulate emissions from these ovens include tars and inorganic ash. Detarring by electrostatic precipitation has been reported at over 99.9% abroad. Close temperature control is required both to fractionally condense the volatile tars, as well as to maintain free-flowing properties of the precipitate. Detarring gas temperatures of from 115°F to 160°F have been reported.20/

Hooding for prebake cells is similar to the vertical stud Soderberg, but ventilation rates are much greater. One exception to this generalization is the Pechiney process which employs no local exhaust ventilation over cells at all, but instead relies upon roof-monitor emissions control to collect pollutants.

Particulate emissions from prebake pots contain none of the tar found in the horizontal stud Soderberg; instead, "dusting" of the carbon anode produces carbon particles in addition to alumina, etc. Current controls have consisted of dry-type cyclones or electrostatic precipitators followed by wet scrubbers. Scrubbers are 12 to 15 ft. in diameter and 40 to 60 ft. high with internally mounted spray headers.

The newest controls being developed have relied upon a dry absorption of fluoride gases (and perhaps particulates) upon finely divided alumina powders. The alumina dust and any other particulate are then collected in a baghouse, and the catch is sent to the cell as the feed. A solid particle coating of alumina on the inside bags also aids in fluoride collection. Dry collection avoids all the plugging and high water costs of scrubbing towers, while allowing the dust to be returned directly to cells in a dry form. Performance data are extremely scarce on this unit as it is still in the development stages, but total particulate collection of 99% and gaseous fluoride efficiencies of 95% have been estimated.

13.5.3.4 Efficiency of Current Potline Controls: Efficiency data for current and prototype control devices are summarized in Table 13.11. Existing particulate control efficiencies vary from 40 to 60%, except where an electrostatic precipitator is used in conjunction with other devices.

TABLE 13-11

CURRENT AND NEWEST AIR POLLUTION CONTROLS FOR PRIMARY ALUMINUM POTLINE AIR POLLUTION CONTROLS[12]

Type of Cell	Existing Collectors	Est. Removal Efficiencies, %		Latest Collectors	Est. Removal Efficiencies, %	
		Fluorides[a]	Particulates		Fluorides[a]	Particulates
H.S.[b]	Soderberg Spray scrubbers	80-90	40-50	1. Floating bed scrubber[c]	90	80-90
				2. Wetted plate electrostatic (with conditioning of flue gases)	90	99
Prebake	Multiclones	0	< 60	1. Fluidized alumina contacts cell exhausts, followed by collection in alumina coated baghouse	99	96-98
	Dry electrostatic precipitators		90			
	Spray scrubbers	80-90	40-50[d] < 10[e]	2. Counterflow packed scrubber	90	95
V.S.[f]	Soderberg multiclones	0	< 60	Sieve plate scrubber	95	70
	Spray scrubbers	80-90	40-50			

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[a] Gaseous and particulate fluorides.
[b] H.S. = horizontal stud.
[c] One section of bed employed.
[d] When used after multiclones.
[e] When used after e.s.p.
[f] V.S. = vertical stud.

13.5.3.5 Roof Monitor Controls: Pot fumes that escape collection by the hooding are emitted through roof vents, called monitors. The sources of building ventilation air are usually adjustable louvers located in the building wall along the side to cool the building and sweep contaminants away from worker's breathing zones. Air may also enter through gratings in the floor. The volume of monitor discharges will depend upon the louver adjustment as well as wind speed and temperature difference. Air turnover in the building approaches 30 to 40 changes per hour.

Most aluminum plants presently have no monitor controls. Where controls have been applied, filament mats or screens are placed in the path of monitor fumes and wetted by sprays. Figure 13-18 shows a roof monitor scrubber--no fans are employed. Efficiency of gaseous fluoride collection is reported at 60-70%. No efficiencies for particulate collection have been reported. However, it is doubtful that much, if any, total particulate collection occurs, given the low pressure drop of the scrubber.

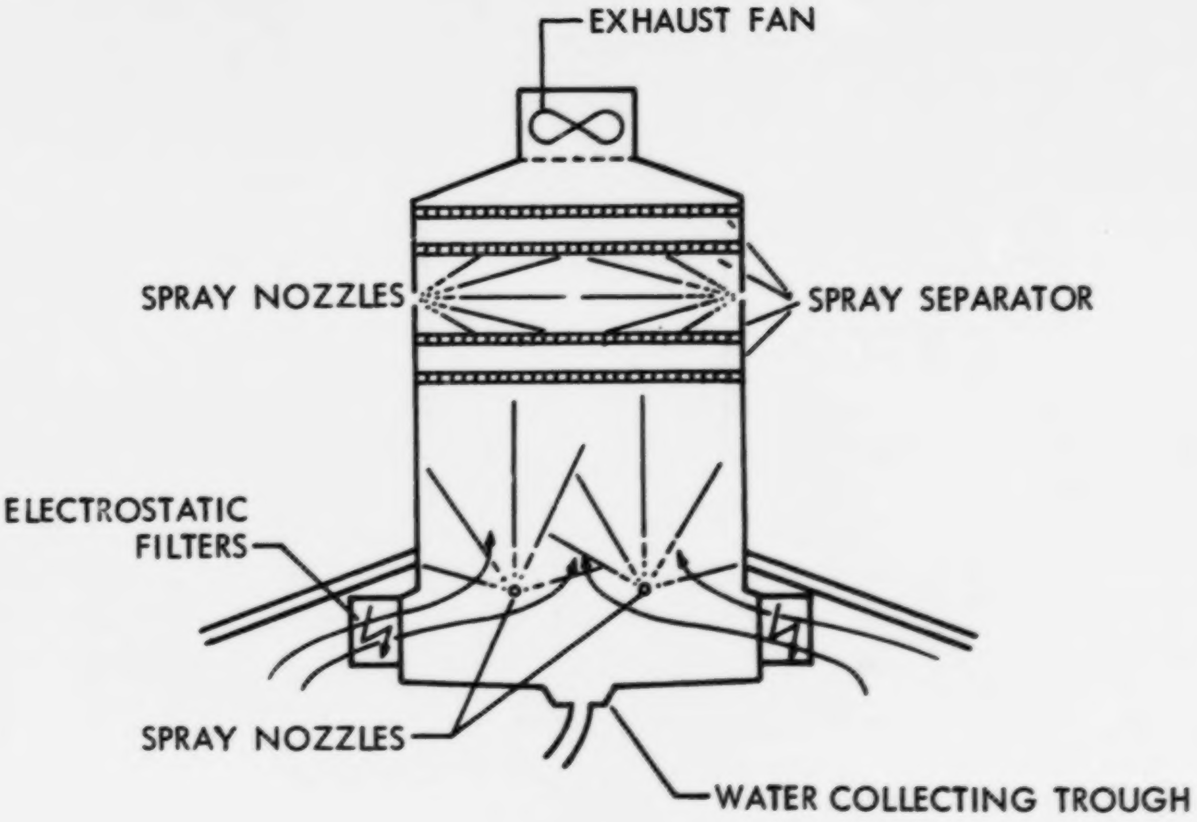

Figure 13-18 - Roof Scrubbers[12]

A more advanced version of the spray chamber scrubber has been reported in the German literature. The spray mats are preceded by electrostatic filters to remove particulate and spray scrubbers dispensing water over wire mesh. Nozzles are positioned so as to clean the mesh of particulate matter and prevent clogging. Ninety percent removal of gaseous fluoride is reported, but no figures are given for particulate matter. Exhaust fans are mounted at the outlet of the spray chamber.

For the plant practicing no hooding ventilation (Pechiney process) and instead emitting all fumes from the monitor, washers appear to be similar to the German roof monitors. However, no electrostatic prefilter is present, and the sprays are horizontal rather than vertical. No collection efficiencies have been supplied for the Pechiney process controls.

13.5.3.6 Other Sources: In addition to roof monitors and potlines, aluminum plants also emit particulates and gases from auxiliary operations. Data on emissions and possible control systems for other sources are even scarcer than for the reduction cell exhaust. In prebake plants, the anode furnace is a source of fluoride, sulfur dioxide, and particulate emissions. In the prebake furnace, carbon anodes are baked for periods of two or three weeks prior to their use in the reduction cell. Natural gas is usually employed to bake the anodes. Existing controls consist of the spray scrubber, which is efficient in removing fluorides and fairly efficient for control of sulfur dioxide, but the controls are, unfortunately, very poor for particulate emissions control. In fact, one plant in Washington State using Pease Anthony scrubbers on the bake ovens emitted an effluent plume with a No. 3 and No. 4 Ringelmann rating because the relatively inefficient scrubbers cannot touch the fine smoke fume. Incineration, followed by medium pressure drop scrubbing, has been suggested, but natural-gas costs for incineration are regarded by aluminum companies as being prohibitively high. Particulate emissions for an uncontrolled anode furnace are reported at under 5 lb/ton of aluminum produced. Sulfur dioxide emissions will depend upon the sulfur content in the pitch and the coke of the anode.

Aluminum casting furnaces also emit particulate and gas. In the casting furnace aluminum from the primary cells is refined by heating and by chlorination. Products of the reaction are aluminum chloride, aluminum oxide and heavy metal chlorides which are given off as fume. Free chlorine and hydrochloric-acid may also be present in the gases from the casting furnaces. Control of emissions from the casting furnaces present many of the same problems that are present with reduction cell exhausts. One potential control device is a multistage floating bed scrubber.13/ In this system, caustic is used as the scrubbing medium, not only to effect particulate matter removal, but also to react with the acid gases. Reportedly, the particulate can be lowered to 0.04 grain/scf.13/

One piece of data on uncontrolled units estimates emissions at 4 lb/ton of aluminum, expressed as chloride. Uncontrolled units would emit a characteristic white plume.

Other miscellaneous sources in aluminum reduction plants are raw materials unloading in transfer operations which have been controlled by baghouse collectors. One Washington plant has also calculated that coke dust emissions from a coke calciner have been controlled to a 0.8 lb/ton when cyclones are used.

13.5.3.7 Control Costs: Literature data on the cost of control devices for the aluminum industry are sparse. One plant manager in Washington State produced information that a recent installation of a new potline resulted in an expenditure of 14% of the capital cost for control devices. However, these devices do not meet regulations currently being imposed or contemplated by regulatory agencies in Washington State.

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CHAPTER 14

CLAY PRODUCTS

14.1 INTRODUCTION

The clay product, or ceramic, industries have as their finished materials a variety of articles that are essentially silicates. These products may be classified as: (1) whitewares; (2) heavy clay products; (3) refractories; (4) enamels and enameled metal; and (5) glass. The three main raw materials used in making common ceramic products are: (1) clay, (2) feldspar, and (3) sand. In addition, a wide variety of other minerals, salts, and oxides (borax, soda ash, cryolite, alumina, chromite, and magnesite) are used as fluxing agents and special refractory ingredients.

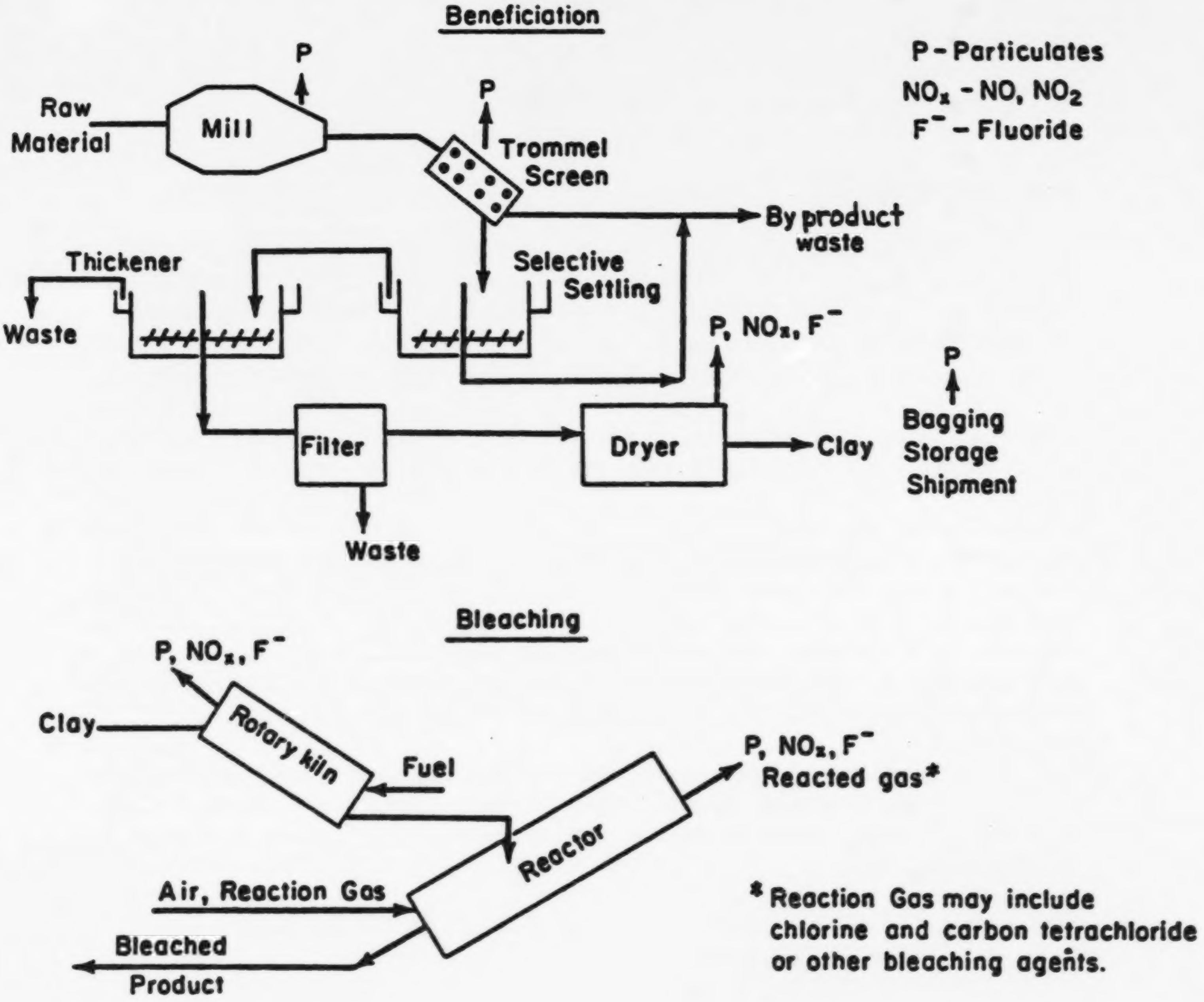
Clay or ceramic products are manufactured by a series of processes involving grinding, screening, calcining, blending of the raw materials, forming, drying or curing, firing, and final cutting and shaping. Particulate emissions occur during handling of raw materials, grinding, calcining, screening and blending, and during cutting and shaping operations. Meager data were found for emission rates from these sources. The particulate air pollution potential of this industry group is not well defined.

Manufacturing processes, particulate emission sources, particulate emission rates, effluent characteristics, and control practices and equipment for the major portions of the clay products industry are discussed in the following sections.

14.2 MANUFACTURING PROCESSES

14.2.1 Ceramic Clay

The manufacture of ceramic clay involves the conditioning of the basic ores by several methods. These include the separation and concentration of the minerals by screening, floating, wet and dry grinding and blending of the desired ore varieties (Figure 14-1). The basic raw materials in ceramic clay manufacture are kaolinite ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$) and montmorillonite (Mg, Ca) $O \cdot Al_2O_3 \cdot 5SiO_2 \cdot \underline{n}H_2O$) clays. These clays are refined by separation and bleaching, blended, kiln dried, and formed into such items as whiteware, heavy clay products (brick, etc.) and various stoneware and other products, e.g., diatomaceous earth used as a filter aid.[2]



* Reaction Gas may include chlorine and carbon tetrachloride or other bleaching agents.

Figure 14-1 - Ceramic Clay Manufacturing Processes[2/]

Halide bleaching for preparation of kaolinite utilizes the reactivity of the halide to remove the chemically active and unwanted constituents of the clay ore leaving behind a purified white product suitable for ceramics manufacture. Figure 14-1 includes a schematic diagram of this process.2/

The manufacture of filter and activated clays includes grinding and wet or acid treating, followed by drying and regrinding. The drying is accomplished in rotary kilns, which reduce moisture content from 15-20% to 10%.

Ceramic clay is manufactured from a mixture of wet talc, whiting, silica clay, and other ceramic materials. This mixture is dried in a spray dryer.

14.2.2 Heavy Clay Products

The manufacture of brick and related products such as clay pipe, pottery, and some types of refractory brick involves the grinding, screening, blending of raw materials, forming, drying or curing, firing, and final cutting or shaping.2/ Bricks are manufactured by one of three processes: the soft-mud, the stiff-mud, or the dry process. The soft-mud process consists in molding the clay mixture containing 20-30% water in molds coated with a thin layer of either sand or water to prevent sticking. The molded brick is then burned. This soft-mud process is used for firebrick.1/

In the stiff-mud process, the clay is just wet enough (12-15%) to stick together when worked. The clay is forced out through a die in a screw or auger machine.1/ The extruded clay bar passes along a short belt conveyor onto a cutting table, on which a frame with a number of wires automatically cuts the bar into appropriate lengths. The bricks are then burned.1/

The stiff-mud process is employed for the manufacture of practically every clay product, including all types of brick, sewer pipe, drain tile, hollow tile, fireproofing, and terra cotta. The greater percentage of clay ware is made by the stiff-mud process.1/

In the dry-press process the water content is from 4-7%, which makes the clay relatively nonplastic. The brick unit is molded at pressures around 5 tons/sq in. and then dried.

The drying and firing of bricks, both common and refractory, is accomplished in many types of ovens. The most popular type is the long tunnel oven in which the bricks, loaded on steel carts, pass countercurrently against the heat flow. Total heating time varies, but is usually

50-100 hr. for 9 in. refractory bricks. Normally gas or oil fuel is used for heating, but coal may be used. Temperatures up to about 2000°F are used in firing common brick.

14.2.3 Refractories

Refractories are those materials which are used to withstand the thermal, chemical, and physical effects that occur in furnaces. Refractories are sold in the form of firebrick, silica brick, magnesite brick, chromite brick, magnesite-chromite brick, zirconia refractories, and others. In making a refractory, the main material is selected on the basis of the thermal, chemical, and mechanical conditions to be encountered in service applications.1/

The usual operations in manufacturing refractories include grinding and screening, calcining, mixing, pressing or molding and repressing, drying, and burning. Usually the most important single property required is high-bulk density, which affects many of the other important properties.

The multiplicity of refractory products results in a highly variable process flowsheet. Depending upon the desired product, raw materials may be calcined or dried prior to mixing and blending. Figure 14-2 illustrates an overall flowsheet for a typical plant producing a kiln-fired refractory.3/ The decision to calcine or dry the raw material depends upon its end use. The type of clay, refractory brick, and ultimate density are among the factors that influence the decision.3/

Castable or fused-cast refractories are manufactured by carefully blending such components as alumina, zirconia, silica, chrome, and magnesia, melting the mixture in an electric-arc furnace at temperatures of 3200-4500°F, pouring into molds, and slowly cooling to the solid state. Fused refractories are less porous, and more dense than kiln-fired refractories.2/

Castable refractories are employed in glass furnaces, as linings of hot zones of rotary kilns, in boiler furnaces exposed to severe duty, and in metallurgical equipment such as forging furnaces.1/

14.3 EMISSION SOURCES AND RATES

14.3.1 Ceramic Clay

Particulate emissions occur from raw materials handling, grinding, drying, and firing kilns. Fluorides and acid gases may also be emitted in the drying process. Factors affecting emissions include type and quantity of material processed, the type of grinding (wet and dry), the temperature

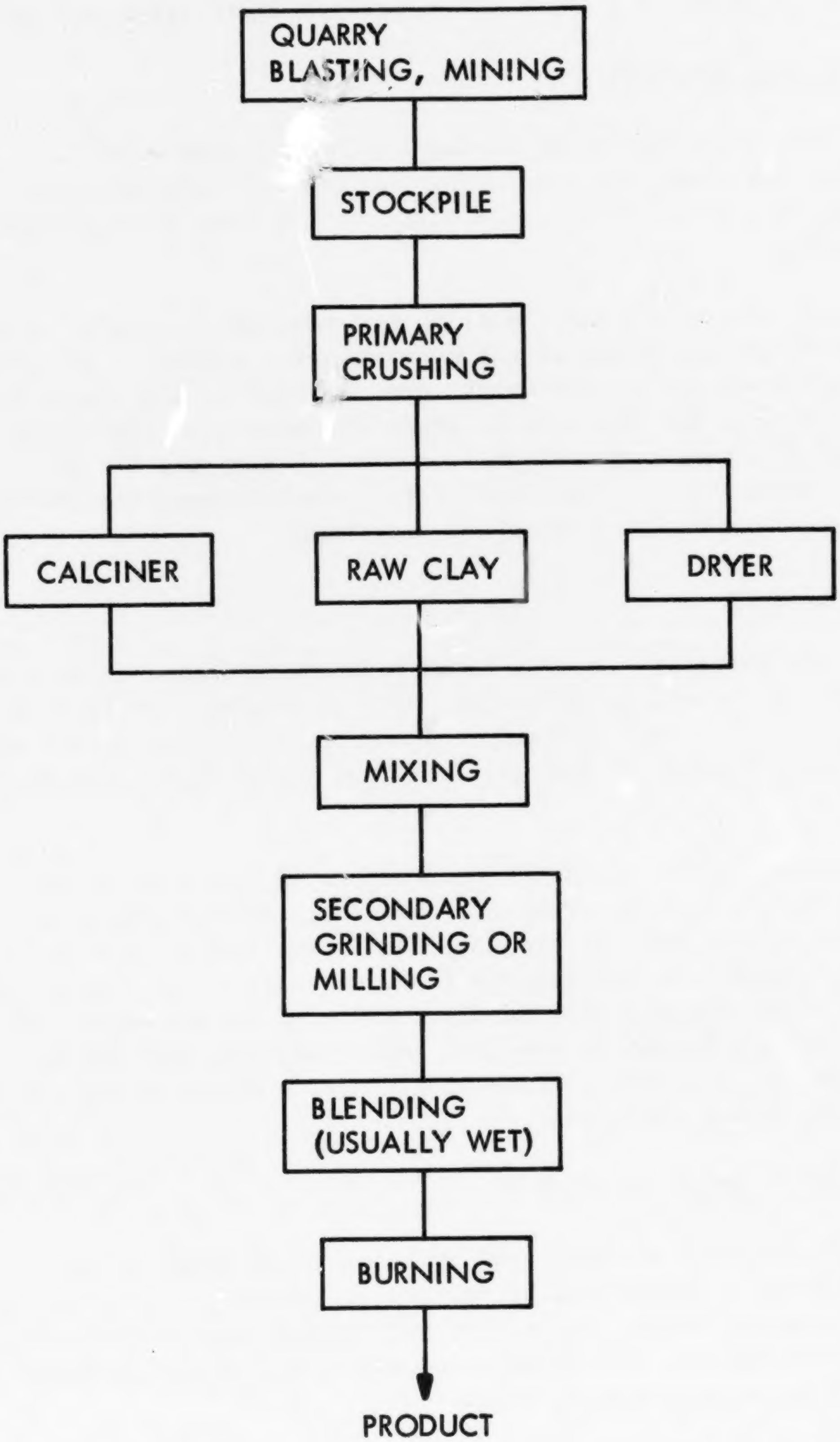


Figure 14-2 - Refractories Manufacture Flow Diagram [3]

of the drying kilns, gas velocities in the drying kilns, the flow direction in drying kilns, and the amount of fluorine in the ores.[2] Insufficient data exist to determine if there is a correlation between dryer types and emissions.

14.3.2 Heavy Clay Products

Particulate emissions occur during handling of raw materials, grinding, screening, and blending, and during cutting and shaping operations. Fluorides, largely in a gaseous form, are also emitted from brick manufacturing operations.[2]

The extent of raw material handling and processing greatly affects the dust emissions from this phase of the manufacturing process. Emissions when firing and/or curing the formed bricks are affected by the temperature in the ovens and the type and quantity of trace components in the brick. Thus, sulfur and/or fluoride compounds may be emitted when the bricks are subjected to high temperatures. The type of fuel used to heat the ovens also has a direct bearing on the combustion emissions.

14.3.3 Refractories

Particulate emissions in kiln-fired refractory plants occur from raw materials handling, crushing, calcining, drying, mixing, and burning operations. Emissions from the calcining and drying operations depend upon the type and quantity of material charged, kiln and dryer types, and final moisture content.

Particulate emissions from the manufacture of castable refractories are created by the drying, crushing, handling, and blending phases of this process, the actual melting process, and in the molding phase. Fluoride emissions, largely in the gaseous form, may also occur during the melting operations. Particulate emissions are affected by the amount of material handling and pre-treatment required before melting, and by the components in the melt. Generally, increasing concentrations of silicon will cause increased particulate emissions.

14.3.4 Summary of Emission Rates

Table 14-1 presents a summary of emission rates from the manufacture of clay products. Current emissions are estimated at 467,000 tons. Data available on emission rates, processing variations, and control equipment practices and utilization are meager, and emission figures in Table 14-1 are considered to be engineering estimates.

TABLE 14-1

PARTICULATE EMISSIONS
CLAY PRODUCTS

Source	Quantity	Emission Factor	Efficiency of Control C_c	Application of Control C_t	Net Control $C_c \cdot C_t$	Emissions tons/yr
I. Ceramic Clay	7,870,000 tons					
A. Grinding	60% of ceramics	76 lb/ton prod.	--	--	0.60	72,000
B. Drying	100% of ceramics	70 lb/ton prod.	--	--	0.60	110,000
II. Refractories	3,440,000 tons					
A. Kiln-Fired						
1. Calcining	20% of kiln-fired	200 lb/ton prod.	--	--	0.64	25,000
2. Drying	30% of kiln-fired	70 lb/ton prod.	--	--	0.64	13,000
3. Grinding	100% of kiln-fired	76 lb/ton prod.	--	--	0.64	47,000
B. Castable Refracts.	550,000 tons	225 lb/ton prod.	--	--	0.77	14,000
C. Dead-Burned Magnesite	125,000 tons	250 lb/ton prod.	--	--	0.56	7,000
D. Mortars	120,000 tons					
1. Grinding		76 lb/ton prod.	--	--	0.60	2,000
2. Drying		70 lb/ton prod.	--	--	0.60	2,000
E. Gunning Mixes	250,000 tons	76 lb/ton prod.	--	--	0.60	4,000
III. Heavy Clay Products	23,700,000 tons					
A. Grinding	20% of heavy clay	76 lb/ton prod.	--	--	0.60	72,000
B. Drying	30% of heavy clay	70 lb/ton prod.	--	--	0.60	99,000
	Total for Clay Products					467,000

Note: Values reported for net control are assumed numbers.

14.4 EFFLUENT CHARACTERISTICS

Limited data were found on the chemical and physical properties of effluents from clay products manufacture. Available data are presented in Table 14-2.

Emissions from the electric-arc furnace are condensed fume and consist of very fine particles, largely 2 μ or smaller.[2/] Kaolin and bauxite particulates emitted from rotary calcining kilns range from 25-40 wt. % less than 10 μ, while particulates from a magnesite kiln may be 50 wt. % < 10 μ.

14.5 CONTROL PRACTICES AND EQUIPMENT

Common control techniques for the ceramic clay manufacturing processes include settling chambers, cyclones, wet scrubbers, electrostatic precipitators and bag filters. Cyclones for the coarser material followed by wet scrubbers, bag filters or electrostatic precipitators for dry dust are the most effective control techniques.

A variety of control systems may be used to reduce both particulate and gaseous emissions from heavy clay products manufacturing. Almost any type of particulate control system will reduce emissions from the materials handling process. However, good design and hooding are required to capture the emissions. Fluoride emission can be reduced to very low levels by using a water scrubber.[2/]

The general types of particulate controls may be used on the materials handling aspect of refractory manufacturing. However, emissions from the electric-arc furnace are largely condensed fume and consist of very fine particles, largely 2 μ or smaller. Baghouses may be used to control particulate emissions from the furnace.[1/]

Multicyclones, baghouses, and electrostatic precipitators have been used on rotary and vertical kilns in kiln-fired refractory plants.[3/]

TABLE 14-2

EFFLUENT CHARACTERISTICS - MANUFACTURE OF CLAY PRODUCTS*

A. Particulate

Source	Particle Size	Solids Loading	Chemical Composition	Particle Density	Electrical Resistivity	Moisture Content	Toxicity
Refractories							
a. Bauxite calcine kiln	25-40 < 10						
b. Magnesite calcine kiln	50 < 10						
c. Electric arc furnace	100 < 2						

B. Carrier Gas

Source	Flowrate	Temperature	Moisture Content	Chemical Composition	Toxicity	Corrosivity	Odor	Flammability or Explosive Limits	Optical Properties
Ceramic Clay									
a. Rotary dryer	a) 23.8 (one dryer)	66							
b. Kiln and cooler	a) 23.9-27.3 (two units)	159-160							
c. Spray dryer	a) 10.5 (one unit)	244							

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* See Coding Key, Table 5-1, Chapter 5, page 45, for units for individual effluent properties.

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CHAPTER 15

FERTILIZER MANUFACTURE

15.1 INTRODUCTION

Fertilizer consumption has increased so rapidly in the past quarter century that manufactured fertilizer has become the major product of the chemical industry throughout the world. The primary manufactured fertilizers are phosphates, nitrates, ureas, and sulfates.

The pollution potential of a fertilizer plant can be divided into separate types: coarse dust, wet solids, odorous or corrosive gases, and vapors. Emissions result from roasting, acidulation processes, drying, granulation, and blending operations.

Manufacturing processes, particulate emission sources, particulate emission rates, effluent characteristics, and control practices and equipment for each major fertilizer category are discussed in the following sections.

15.2 PHOSPHATE FERTILIZERS

15.2.1 Phosphate Rock Preparation

Phosphate rock preparation involves beneficiation to remove impurities, drying to remove moisture, and grinding to improve reactivity. Phosphate rock deposits have widely varying compositions and properties. The presence of a high content of organic matter is undesirable. Organic matter tends to stabilize a foam blanket on the surface of the acid reactors, and it produces a slimy gypsum filter cake which is slow filtering and difficult to wash. Organics are removed by roasting the rock between 1200 and 1600°F. The roasting is done in a variety of furnaces.

Usually, direct-fired rotary kilns, 25-100 ft. long, 8-10 ft. in diameter, are used to dry phosphate rock (Figure 15-1). These dryers use natural gas or fuel oil as fuel and are fired countercurrently. From the dryers, the material may be ground before storage and is finally conveyed to large storage silos. Emissions from these processes consist primarily of fine rock dust, but some sulfur dioxide may be present in the dryer exhaust from the combustion of sulfur in the fuel.

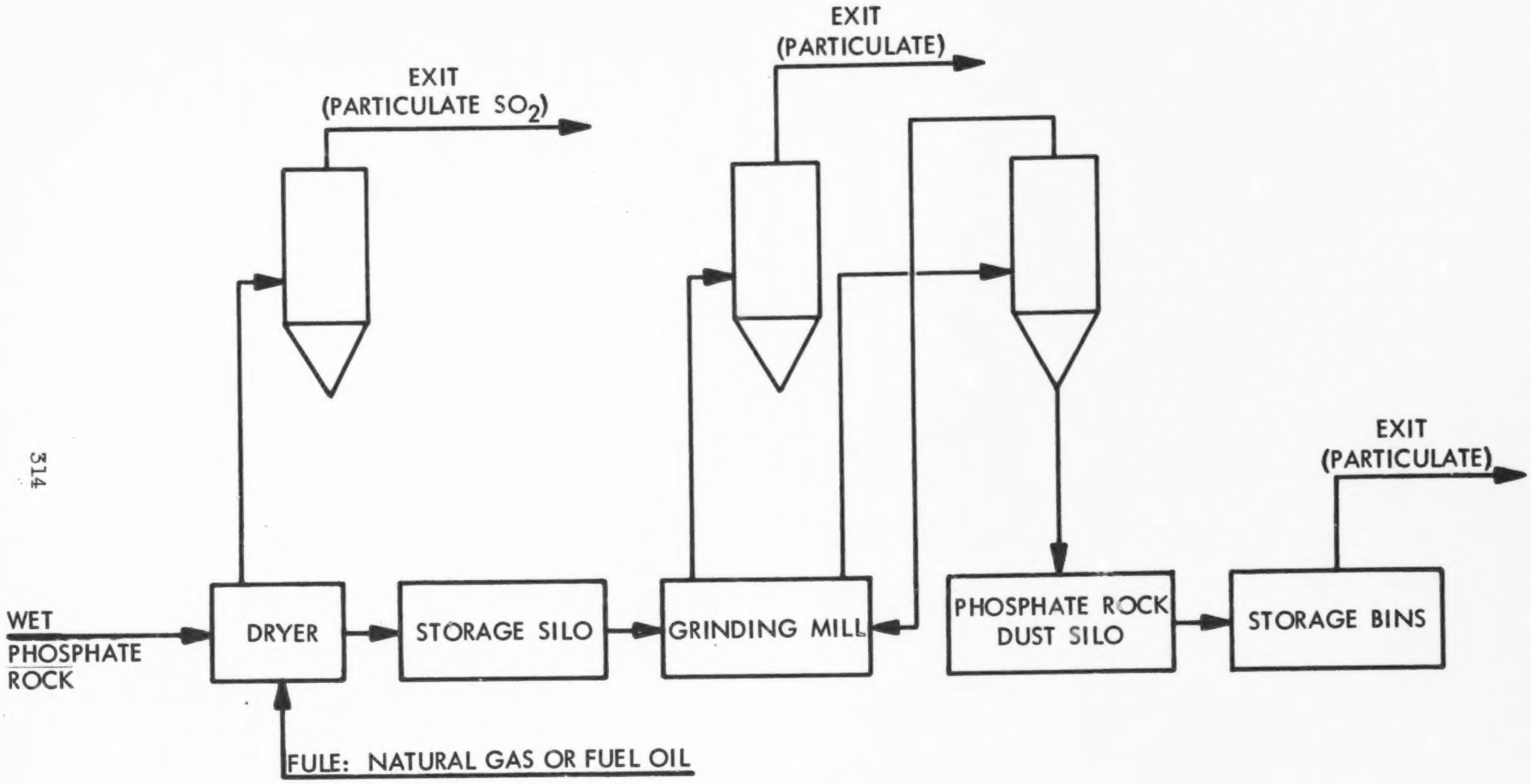

Figure 15-1 - Flow Diagram of Phosphate Rock Storage and Grinding Facilities, Noting Potential Air Pollution Sources

Other points of emission in a phosphate rock grinding and preparation plant are transfer points on conveying systems and discharge points at storage hoppers and silos.

15.2.2 Wet Process Phosphoric Acid

Wet-process acid is produced by treating fluorapatite $[Ca_{10}(PO_4)_6F_2]$ or phosphate rock, with sulfuric acid. Phosphoric acid is formed, calcium sulfate is precipitated and filtered off, and the acid is concentrated from about 32% P_2O_5 to about 54% P_2O_5. Virtually all the wet-process acid produced in this country is used in the manufacture of various phosphate fertilizers.6/

Most current process variations for producing wet-process phosphoric acid depend on decomposition of phosphate rock by sulfuric acid under conditions where gypsum ($CaSO_4 \cdot 2H_2O$) is precipitated. Several variants of this process are offered by various contractors. The Dorr-Oliver, St. Gobain, Prayon, and Chemico processes are among the better known.6/ In spite of the number of contractors in the field, new plants do not seem to differ fundamentally among themselves. In addition, several general trends are evident, such as the use of single-tank instead of multiple-tank reactors, one or two large horizontal tilting-pan filters, large plants of 1,000 ton/day capacity and more, and closed systems where atmospheric emissions are minimized. Figure 15-2 is a flow diagram of a modern, wet-process phosphoric acid plant.6/

Finely ground phosphate rock is metered accurately and continuously into the reactor, and sulfuric acid is added. The single-tank reactor illustrated in Figure 15-2 is a circular, two-compartment system wherein reactants are added to the annular volume and the central volume is used for growing gypsum crystals. Some years ago, plants were built with several separate reaction tanks connected by launders, which are channels for slurry flow. The tendency now is to use a single tank with several compartments. In some of these designs, the slurry flows over and under a series of baffles.

Proper crystal growth depends on maintaining sulfate ion concentration within narrow limits at all points in the reaction slurry. The proper sulfate ion concentration appears to be slightly more than 1.5%. Lower levels give poor crystals that are difficult to filter; higher concentrations interfere with the reaction by causing deposition of calcium sulfate on unreacted rock. Good reactor design will prevent sudden changes of sulfate ion concentration, will maintain this concentration and temperature near optimum, and will provide sufficiently long holdup time to allow growth of large, easily filterable crystals without the formation of excessive crystal nuclei.

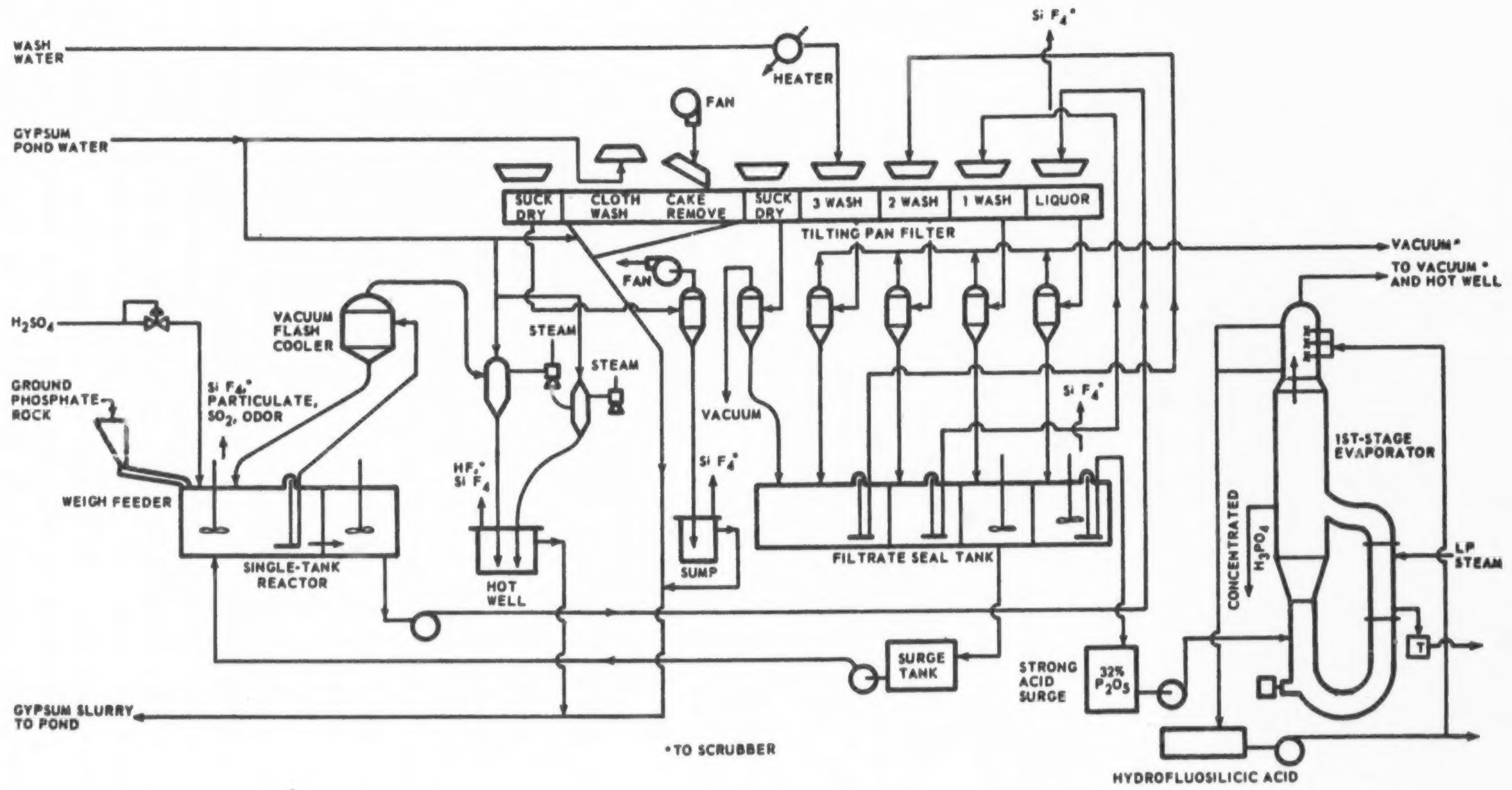

Figure 15-2 - Flow Diagram Illustrating Wet-Process Phosphoric Acid Plant[6]

Concentrated sulfuric acid is usually fed to the reactor. If dilute acid is used, its water content must be evaporated later. The only other water entering the reactor comes from the filter-wash water. To minimize evaporation costs, it is important to use as little wash water as is consistent with practical H_3PO_4 recoveries.

Considerable heat of reaction is generated in the reactor and must be removed. This is done by blowing air over the hot slurry surface or by vacuum flash cooling part of the slurry and sending it back into the reactor. Modern plants use vacuum flash cooling. Figure 15-2 illustrates this method of cooling.

The reaction slurry is held in the reactor for periods up to 8 hours, depending on the rock and on reactor design, and is then sent to be filtered. The circular, horizontal, tilting-pan vacuum filter is illustrated in Figure 15-2. Older and smaller plants may use other types of filters.

In washing the resultant gypsum cake on the tilting-pan filter, wash water flow is countercurrent to the rotation of the cake, and heated fresh water is used to wash the "cleanest" cake. These filters can be built in very large sizes, and designs are now approaching 1,000 ton/day P_2O_5 capacity.

The 32% acid from the filter generally needs concentrating for further use. Current practice is to concentrate it to 54% by evaporation in two or three vacuum evaporators.

15.2.2.1 Emissions from Wet-Process Phosphoric Acid Manufacture: Emissions from wet-process phosphoric acid manufacture consist of rock dust, fluoride gases, particulate fluoride, and phosphoric acid mist, depending on the design and condition of the plant. Fluorine exists as various compounds in the collection equipment; as fluorides, silico-fluorides, silicon tetrafluoride, and mixtures of the latter and hydrogen fluoride, the mole ratio of which changes in the vapor with the concentration of fluorosilicate in the liquid and with temperature. Because of the complex chemistry, the composition of emissions is variable.

The reactor, where phosphate rock is decomposed by sulfuric acid, is the main source of atmospheric contaminants. Acid concentration by evaporation provides another source of fluoride emissions. The filter is a third source of fluoride emissions. For circular filters, and for filters of the Georgini pan-filter type, most of the emissions are at feed and wash points. Emissions from filters are not large and can be controlled by the use of hoods, vents, and scrubbers.

In addition to these three main sources of emissions, there are many miscellaneous minor sources. These include vents from such sources as acid splitter boxes, sumps, and phosphoric acid tanks. Collectively, these sources of fluoride emissions are significant, and they are often enclosed and vented to a suitable scrubber.

15.2.3 Normal Superphosphate Production

"Normal superphosphate" is the term applied to the fertilizer produced by reacting sulfuric acid with phosphate rock. Normal superphosphate contains from 16 to 21% phosphoric anhydride (P_2O_5).

While there have been developments and refinements, the three basic steps in the production of normal superphosphate have remained the same over the years (Figure 15-3). Sulfuric acid and rock are intimately mixed, dropped into a den, held for sufficient time to allow the slurry mixture to set into a solid porous form, and stored to permit the acidulation to go to completion. Plants are described as batch or continuous, depending upon the type of den used. Over 75% of U.S. plants use the batch process.

Following the curing period, three alternates are available: (1) the product can be ground and bagged for sale; (2) the cured superphosphate can be sold directly as run-of-pile product; or (3) the material can be granulated for sale as granulated superphosphate or used as a component of granular mixed fertilizer.

For the latter alternative, normal superphosphate is blended with some or all of the following ingredients--ammonia, sulfuric acid, phosphoric acid, triple superphosphate, potash. Steam or water is added, if needed, to aid in granulation. The mixture is then passed through a rotary dryer, which removes sufficient moisture to eliminate the chance of the pellets binding together. From the dryer the material passes through a rotary cooler and is conveyed to storage bins for sale as a bagged or bulk product.

The gases released from the acidulation of phosphate rock contain silicon tetrafluoride, carbon dioxide, steam, and sulfur oxides. From 20 to 28% of the total fluoride in the phosphate rock is evolved in the acidulation and curing operation. Curing building emissions are not usually controlled in normal superphosphate plants.

Vent gases from a granulator-ammoniator may contain ammonia, silicon tetrafluoride, hydrofluoric acid, ammonium chloride, and fertilizer dust. Emissions from the dryer will include gaseous and particulate fluorides, ammonia, and fertilizer dust. Some emissions will also contain sulfur oxide, especially if high-sulfur oil is used as fuel to the dryer. Emissions from the cooler will contain primarily fertilizer dust, and may also include traces of the aforementioned pollutants.

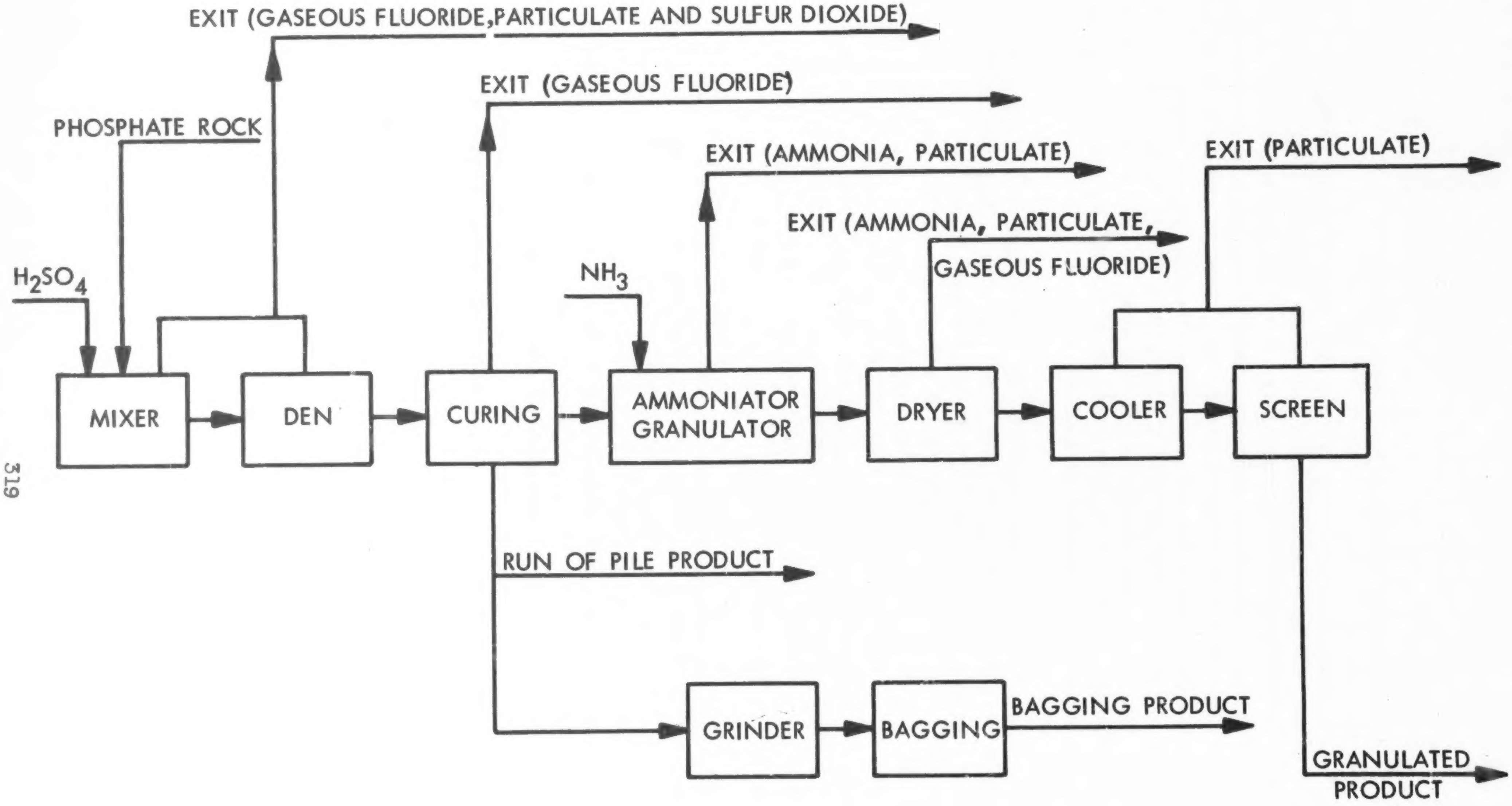

Figure 15-3 - Flow Diagram of Normal Superphosphate Plant, Noting Potential Air Pollution and Sources. Control devices are not shown.

15.2.4 Triple Superphosphate Production

"Triple superphosphate" is the popular name for the product resulting from the reaction between phosphate rock and phosphoric acid. Unlike normal superphosphate, the production of triple superphosphate is usually a continuous operation in large plants located near phosphate rock deposits. The phosphate rock is ground to a fineness ranging from 80% through a 100-mesh screen to 95% through a 200-mesh Tyler screen. Although either furnace or wet process phosphoric acid may be used as the acidulant, at the present time wet-process acid is used almost exclusively. Concentrated acid with a P_2O_5 content of 50-55% is used. Fluoride content of wet-process acid may be as high as 1-2%.

Two major processes are used in the production of triple superphosphate (Figure 15-4). The first uses a mixing cone to achieve intimate contact between the acid and rock. The resulting mix falls to a conveyor belt which moves the material to the curing building. On its way to the curing building the mix is passed through several mixers or blungers (pug mills) to aid in the contact of the rock and acid as well as to release fluorine vapors. Fluoride-containing fume is collected along the entire length of the belt by a tight hood over the belt, the blungers, and the mixer. After curing for 30-60 days, the product can be sold as run-of-pile (ROP), or it can be granulated in separate equipment.

With the increased demand for granulated products, a second process has been introduced to produce granulated fertilizer directly. In one commercial process, the acid and phosphate rock are placed in mixing tanks, fed through a blunger for intimate mixing and release of some of the effluent gases, and then dried in a rotary dryer using oil or gas as fuel. The product is a directly granulated material which is rather hard and dense and normally not amenable to ammoniating.

Most triple superphosphate is of the nongranular type. The exit gases from a plant producing the nongranular product will contain considerable quantities of silicon tetrafluoride, some hydrogen fluoride, and a small amount of particulates. In cases where ROP triple superphosphate is granulated or mixed as a granulated-mixed fertilizer, one of the greatest problems is the emission of dust and fumes from the dryer and cooler. Screening stations and bagging stations are a source of fertilizer dust emissions in this type of process.

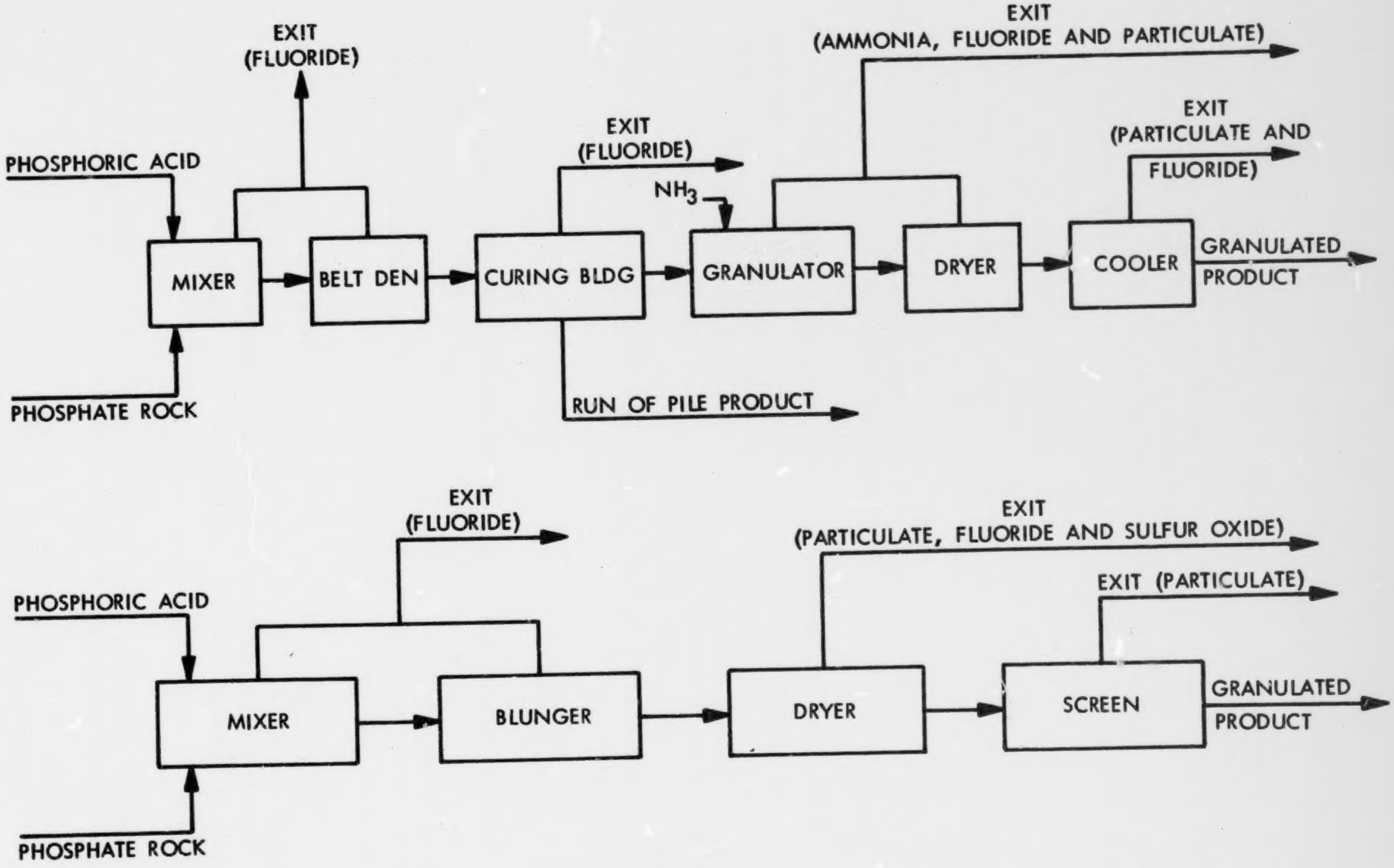

Figure 15-4 - Flow Diagram for Production of Run-of-Pile and Granular Triple Superphosphate, Noting Potential Air Pollution Sources

15.2.5 Diammonium Phosphate Production

In the manufacture of diammonium phosphate the initial reaction between ammonia and phosphoric acid takes place in a reactor tank lined with acid brick (Figure 15-5). Both acid from the gas scrubbers and fresh acid are used as feedstock. In many plants some 93% sulfuric acid is used to control the composition of the final product. The relative amounts of phosphoric and sulfuric acid usually depend on the purity of the incoming phosphoric acid. The product of the reactor is pumped as a slurry to a rotary ammoniator. In the ammoniator additional ammonia is sparged underneath the mixing bed to achieve a final mole ratio of 1.8 to 2.0. While the equipment is rotating, agglomeration takes place and the ammoniation is completed. Diammonium phosphate granules are discharged from the ammoniator to a rotary dryer, thence through a screening station and a rotary cooler to storage. Fines and oversize particles from the screening station are recycled back to the ammoniator for product control.

The major pollutants from diammonium phosphate production are fluoride, particulates, and ammonia. Dust-producing areas are the cage mills, where oversized product from the screens is ground before being recycled to the ammoniator. Dust from these points is usually vented through cyclone collectors, and then to either an impingement or a venturi scrubber. Vent gases from the reactor and ammoniator tanks, which contain high quantities of ammonia, are usually scrubbed with acid to recover the residual ammonia.

15.2.6 Granulation

Granulation is a method of processing that has been widely adopted as a means of improving the storage and handling properties of fertilizer materials and mixtures by increasing their normal particle size to material that will largely be retained on a 16-mesh sieve, and which includes particles in the range of 1 to 4 mm in diameter.

In the granulation of ammonium phosphate fertilizer, a gypsum-acid slurry is obtained by by-passing the filter in a phosphoric acid plant (Figure 15-6). Ammonia is introduced into this slurry and into acidulated phosphate from the acidulation tank. The mixture then flows to the dryer.

After the dryer, the product is screened. Large lumps are crushed and recycled to the granulator along with the fines passing the screens.

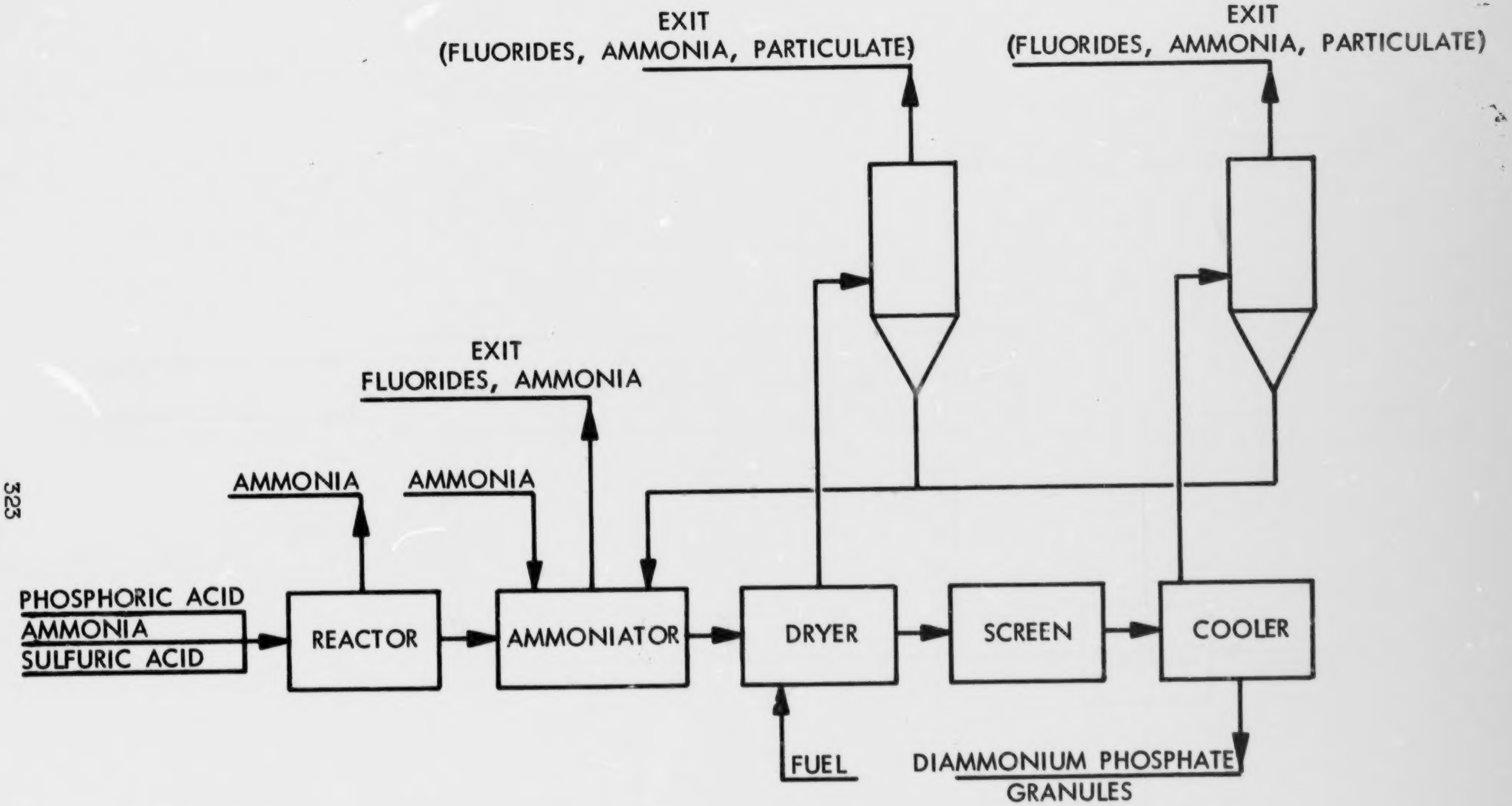

Figure 15-5 - Flow Diagram of Diammonium Phosphate Plant, Noting Potential Air Pollution Sources

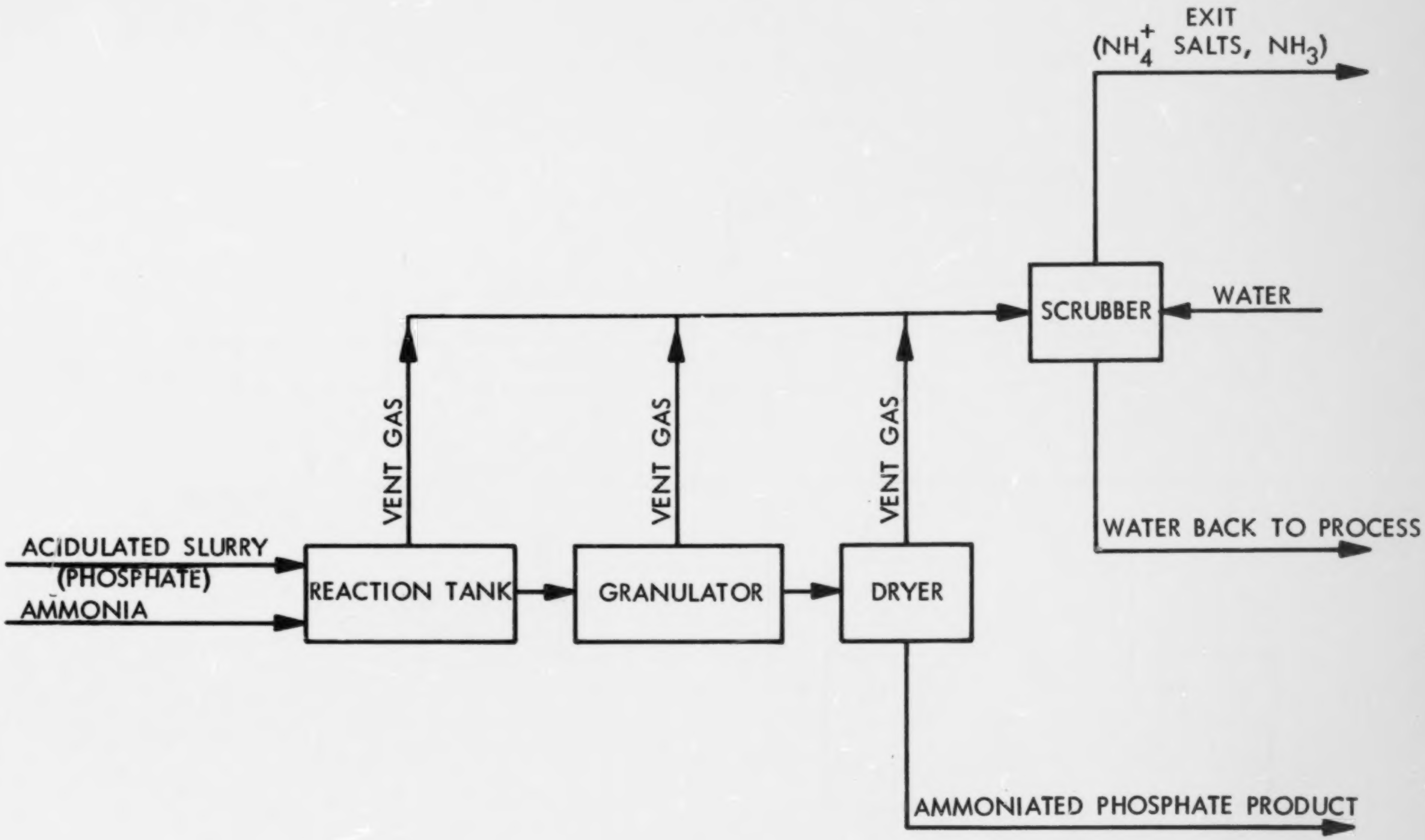

Figure 15-6 - Flow Diagram of the Slurry Granulation Process in the Manufacture of Fertilizer, Noting Potential Air Pollution Sources

Water scrubbers of various types are used for recovery of ammonia and ammonium salts, which are then recycled to the process. The greater portion of the ammonia is recovered. However, ammonium salts are not easily recovered because of their very fine size.

In nonslurry granulation, part or all of the neutralization reaction is carried out in the granulation vessel. The number of sources of air pollution is reduced by elimination of the reaction tanks. This method of granulation is widely used for mixed fertilizers based on superphosphates.

Dust from granulation is mainly from dryers and coolers. Dust from screens, hammermills, and materials handling also is important since the granulation process involves recirculation of material to build up the size of granules. The manufacture of salt grades (fertilizers containing potash) produces a fume of NH_4Cl which is composed of particles $< 5\ \mu$ and is difficult to collect. The amount of chloride fume produced depends on the raw materials used; ammoniating solutions and sulfuric acid tend to increase the amount of fume.

15.2.7 Emission Rates from Phosphate Fertilizer Manufacture

Particulate emission rates from the various processes comprising phosphate fertilizer manufacture are summarized in Table 15-1. Both fluoride particulate and fertilizer dust are included in the emissions. Dust losses from materials handling operations are estimated at 2 lb/ton of granulated material.

15.3 AMMONIUM NITRATE FERTILIZER

Commercial processes for the manufacture of ammonium nitrate depend almost entirely on the neutralization of nitric acid with ammonia in liquid or gaseous form (Figure 15-7). Synthetic ammonia, as the anhydrous liquid, and nitric acid produced from the oxidation of ammonia are used.

Essentially three steps are involved in producing ammonium nitrate: neutralization, evaporation of the neutralized solution, and control of the particle size and characteristics of the dry product.

TABLE 15-1

PARTICULATE EMISSIONS
PHOSPHATE ROCK AND MANUFACTURE OF FERTILIZER

Source	Quantity of Material	Emission Factor	Efficiency of Control C_c	Application of Control C_t	Net Control $C_c \cdot C_t$	Emissions (tons/yr)
I. Phosphate Rock	41,300,000 tons per year					
A. Dryer		12 lb/ton of end product	0.94	1.0	0.94	14,000
B. Grinder		2 lb/ton of end product	0.97	1.0	0.97	1,000
C. Materials handling		2 lb/ton of end product	0.90*	0.25*	0.22	30,000
D. Calcining		40 lb/ton of end product	0.95	1.0	0.95	8,000
II. Ammonium Nitrate	2,800,000 tons of NH_4NO_3 granules					
A. Evaporator		1 lb/ton of end product				
B. Prilling tower		12 lb/ton of end product				
C. Dryer and cooler						
D. Materials handling						
1. Elevators						
a. boots						
b. heads						
2. Conveyors						
a. transfer points						
b. discharge to bins, silos						
3. Shipment of product						
a. bagging		1 lb/ton (controlled)				
b. bulk loading						
	Total for Ammonium Nitrate	Assume 1% of end product				28,000
III. Urea--same as Ammonium Nitrate	1,000,000 tons of $(NH_4)_2CO$ granules	Assume 1% of product				10,000
IV. Phosphate Fertilizers						
A. Rock pulverizing	17,000,000 tons of phosphate rock	6 lb/ton of rock	0.80	1.0	0.80	10,000
B. Fluoride particulate from acid-rock reaction	4,370,000 tons of P_2O_5 from phosphate rock	46 lb. partic./ton of P_2O_5	0.95	0.95	0.90	9,000
1. Wet-process reactor						
2. Filter						
3. Mixers superphosphate manufacture						
C. Pre-neutralizer						
D. Granulating equipment	18,000,000 tons of granular material					
1. Blunger						
2. Granulator		0.5 lb/ton				
E. Dryer		105				
F. Cooler		90 lb/ton				
		195	0.95	0.95	0.90	169,000
G. Screens						
H. Mills						
I. Materials Handling						
1. Unloading of raw-material shipments						
a. phosphate rock						
b. potash						
2. Conveyors						
a. transfer points						
b. discharge to bins, silos						
3. Elevators						
a. boots						
b. heads						
		2 lb/ton of granular material				18,000
4. Shipment of product						
a. bagging machines	50% of 18,000,000 tons	1 lb/ton (controlled)				4,000
b. bulk loading						
V. Ammonium Sulfate	2,700,000 tons	1% of product*				27,000
A. Crystallizer						
B. Drying						
C. Shipping						
1. Bagging machines						
2. Bulk loading						
	Total for Phosphate Rock and Fertilizer					328,000

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* Assumed.

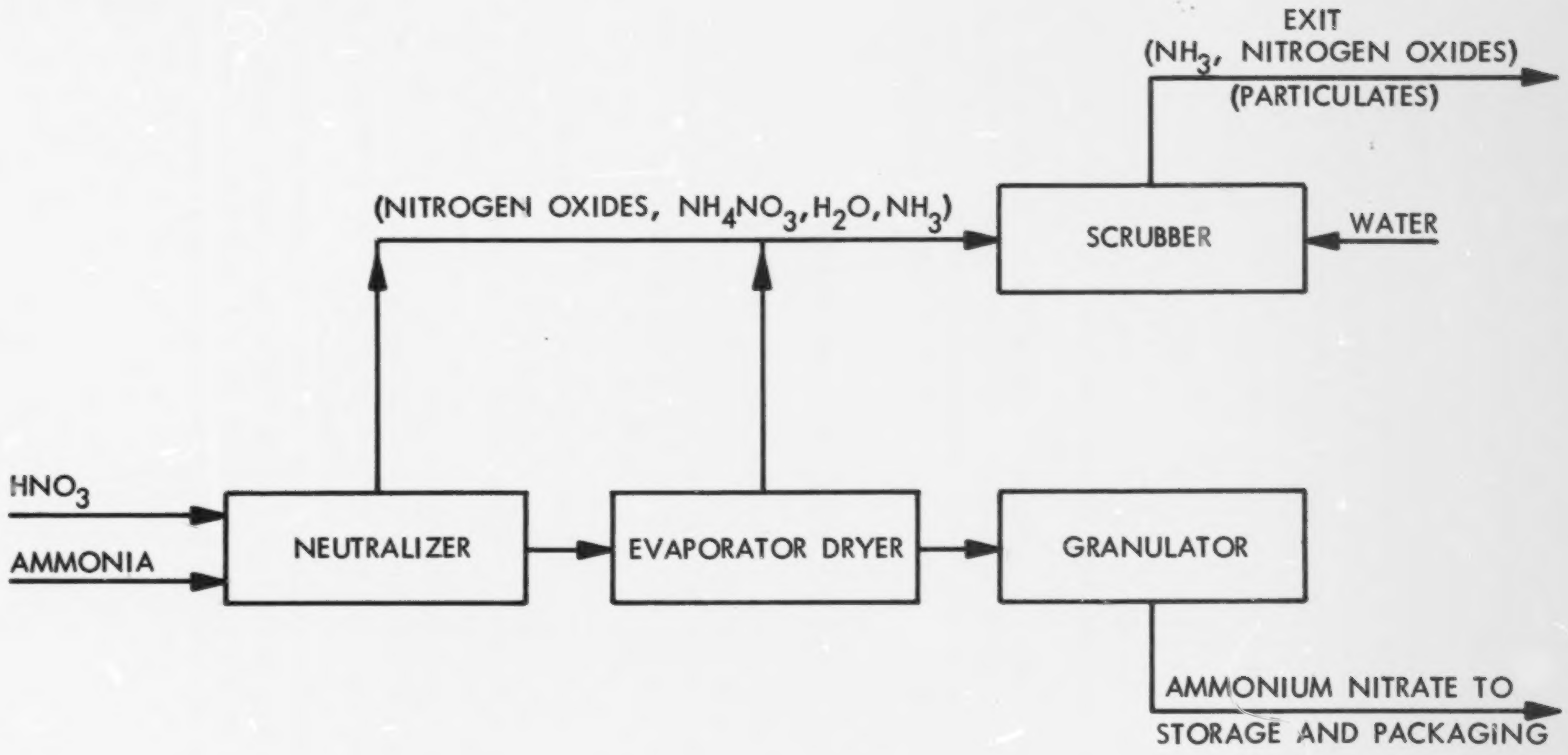

Figure 15-7 - Flow Diagram of the Process for Manufacture of Ammonium Nitrate, Noting Potential Air Pollution Sources

15.3.1 Neutralization

Direct neutralization is practiced when pure reactants are used in an aqueous medium. The reaction of ammonia with nitric acid is strongly exothermic; both reactants are volatile at the resulting elevated temperatures. This condition must be controlled to prevent loss of materials. Usually a slight excess of nitric acid, the less volatile of the two reactants, is maintained during neutralization.

15.3.2 Evaporation

Procedures vary depending on the water content of the reactants and the control of temperatures. In methods formerly in wide use, the neutral ammonium nitrate solution was evaporated to a high degree of concentration, with subsequent cooling and granulation of the product. Other processes carry the evaporation to a lesser degree of concentration and complete the separation of the solid ammonium nitrate by crystallization or, more frequently, by continuous evaporation in specially designed apparatus.

15.3.3 Control of Particle Size and Properties

Various procedures, such as graining, flaking, and spraying, have been practiced over the years to obtain nitrate particles or grains for the final product. The method that has been adopted by the great majority of plants is prilling. Prilling is spray drying of a concentrated solution.

The prilling step is followed by rotary or fluidized-bed drying and cooling. The product prills may then be coated with a clay material, to prevent caking, in a rotary coating drum. These drying and cooling operations use large quantities of heated air which entrains the dust and fines. However, the emissions from these operations are usually controlled with low pressure drop wet scrubbers using dilute salt solutions to collect the material and recycle it back to the process.

The prilling operation may be as large an emission source as the drying and cooling operations. In the prilling process losses are dependent upon the velocity of the air in the prilling tower. Total fines lost from the process can be kept to $< 1\%$ of the product.

15.3.4 Emission Rates from Ammonium Nitrate Fertilizer Manufacture

Particulate emission rates from the manufacture of ammonium nitrate fertilizer are summarized in Table 15-1. Limited data were found for particulate emissions from nitrate fertilizer manufacture, and the emission totals in Table 15-1 are considered as conservative estimates.

15.4 UREA FERTILIZER

The commercial production of urea is based on the exothermic synthesis of ammonium carbamate with its subsequent dehydration to urea. Ammonia and carbon dioxide are reacted together in a high-pressure reactor to form a melt containing urea, ammonium carbamate, and water, along with some unreacted ammonia. Depending upon the particulate process used, the temperature of the melt in the reactor is maintained between 175°C and 210°C and the pressure between 170 atm. and 400 atm.

Eight processes are currently used in the manufacture of urea. The method of treating the off gas (ammonia and carbon dioxide) from the carbamate-urea reactor represents the major differences among the variety of competing processes for the manufacture of urea. Figures 15-8 and 15-9 illustrate two methods of final preparation.

The aqueous solution of urea from any of the processes must be concentrated to remove the excess synthesis water as well as traces of dissolved synthesis gases and then filtered to remove any solid impurities.

15.4.1 Emission Rates from Urea Fertilizer Manufacture

Emission rates for urea fertilizer manufacture are summarized in Table 15-1. No detailed data were found on emission rates, and an emission factor of 1% of the end product was used to estimate the particulate emissions.

15.5 AMMONIUM SULFATE

Most ammonium sulfate produced is a by-product of coke-oven operations. Sulfuric acid is used to scrub the ammonia out of the coke-oven gas and the scrubbing produces an ammonium sulfate solution. The solution is further concentrated, and crystals of ammonium sulfate are extracted in a centrifuge. The crystals are then dried. Since all other operations are carried out in the wet state the only potential source of particulate emission is the dryer. The dryer is usually controlled by cyclones or wet scrubbers.

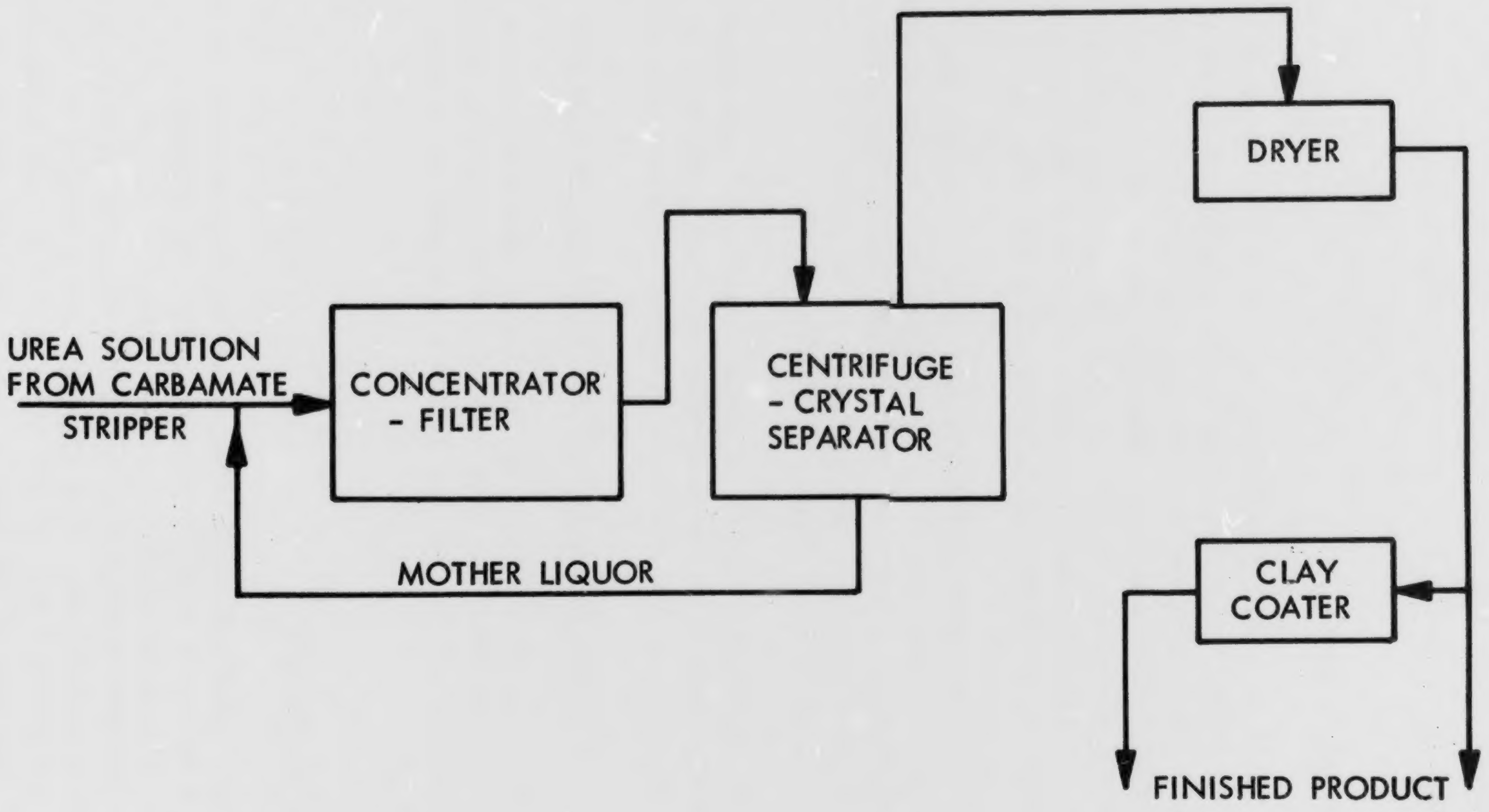
UREA SOLUTION FROM CARBAMATE STRIPPER
CONCENTRATOR - FILTER
CENTRIFUGE - CRYSTAL SEPARATOR
MOTHER LIQUOR
DRYER
CLAY COATER
FINISHED PRODUCT

Figure 15-8 - Sketch of Manufacturing Process for Crystalline Urea Product

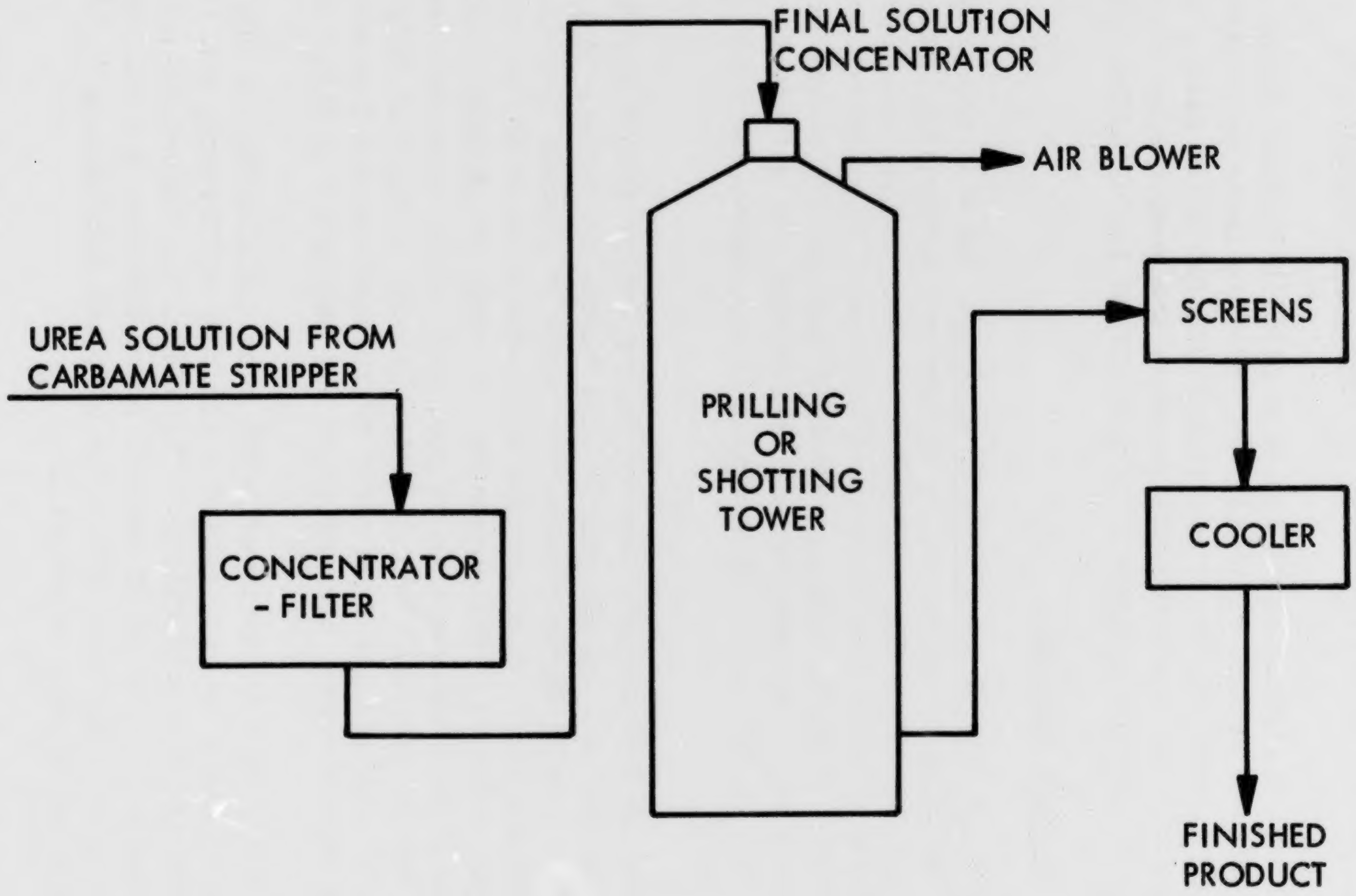

Figure 15-9 - Sketch of Manufacturing Process for Prilled or Shotted Urea Product

15.6 CHARACTERISTICS OF EFFLUENTS FROM FERTILIZER MANUFACTURE

The chemical and physical characteristics of effluents from fertilizer manufacture are summarized in Table 15-2. Particulates emitted from phosphate fertilizer production equipment are hot, moist, partially water-soluble, corrosive, hydroscopic, disagreeable to the sense of smell, and have a tendency to stick to and build up on almost any surface. Dusts emitted from superphosphate dryers are about 12 wt. $\% < 10\ \mu$.

15.7 CONTROL PRACTICES AND EQUIPMENT IN FERTILIZER MANUFACTURE

Control equipment which has been used in various phases of fertilizer manufacture include cloth filters, electrostatic precipitators, and mechanical systems for dust; wet collectors for dust, gases, and fluoride mists.1/ Wet scrubbers are probably the most common piece of dust and fume collection equipment being utilized in fertilizer plants.2/

15.7.1 Control Equipment

15.7.1.1 Wet-Process Phosphoric Acid: Because the principal atmospheric contaminants generated in the process are gaseous fluorides, vapor scrubbing is universally employed to control emissions. Specific devices used for control include Venturi scrubbers, impingement scrubbers, and various kinds of spray towers. Fluoride removal efficiency of these devices varies widely, and staging may be required for satisfactory control. Plugging, or difficulty in removing precipitates and dust, may also be experienced.6/

Table 15-3 summarizes the results of Public Health Service tests conducted on 10 wet-process phosphoric acid plants in various parts of the country.6/ For nine of these plants, the range of gaseous fluoride emissions from various types of collectors was 0.006 to 0.17 lb. of fluoride per ton of P_2O_5 produced. The concentration range of gaseous fluorides in the gases from collectors was 3 to 40 ppm, and 0.0011 to 0.0147 grain/scf for eight of the 10 plants. Public Health Service stack-test data agree reasonably well with results from plant questionnaires and information from miscellaneous sources, both of which are tabulated in Table 15-4.6/

Scrubber efficiency is affected substantially by the loading of the gas stream. Heavy loading enhances scrubber efficiency, and light loading reduces scrubber efficiency. Therefore, scrubber-exit-gas concentration is a better indicator of overall plant emission control than is scrubber efficiency. The best criterion of plant performance is the weight of emission per ton of P_2O_5 produced.6/

TABLE 15-2

EFFLUENT CHARACTERISTIC - FERTILIZER MANUFACTURE+

A. Particulate (Part I)

Source	Particle Size	Solids Loading	Chemical Composition	Particle Density	Electrical Properties	Moisture Content	Toxicity
Fertilizer Industry							
1. Phosphate fertilizer							
a. Phosphate rock							
(1) Rock dryer			Rock dust, typical composition: P_2O_5, 32.5; SiO_2, 11.0; Al_2O_3, 2.0; MgO, 0.7; CaO, 45.5; Fe_2O_3, 0.8.				
(2) Rock grinder			Rock dust, see rock dryer				
(3) Roaster or calciner							
(a) Fluid bed roaster	(Dust from cyclone collector) 26 < 1, 81 < 5, 96 < 10, 100 < 25	6.8					
b. Wet-process acid							
(1) Reactor or digestor		0.47-3.7	Fluoride, acid mist				Fluorides are toxic
(2) Filter		0.017	Fluoride, acid mist				Fluorides are toxic
c. Superphosphate production							
(1) acid reactor (den)		0.09-0.15	H_2SiF_6, SiO_2				Irritating to eyes, nose, and throat
(2) Granulator-ammoniator			NH_4Cl, fertilizer dust				
(3) Dryer	BAHCO analysis: 1-12.2 < 5, avg. 6.3 < 5; 2-26 < 10, avg. 12 < 10; 3-46 < 20 avg. 22 < 20; 5-55 < 30, avg. 29 < 30; 6-61 < 40, avg. 34 < 40	0.7-4.0	Fluorides, fertilizer, Ca, Mg, P, Fe, and Al compounds	1.6-2.5			Fluoride - toxic
(4) Cooler	BAHCO analysis (1 test): 6.2 < 5, 11.1 < 10, 20 < 20, 24.1 < 30, 32 < 40		Fertilizer dust	2.2			
(5) Bagging	BAHCO analysis (1 test): 2 < 5, 3 < 10, 5.8 < 20, 14 < 30 31 < 40						
d. Triple superphosphate production							
(1) Acid reactor			Fluoride				
(2) Granulator			Fluoride, fertilizer dust				
(3) Dryer			Fluoride, fertilizer dust				
(4) Cooler			Fluoride, fertilizer dust				
e. Diammonium phosphate production							
(1) Dryer							
(2) Cooler							
2. Ammonium nitrate fertilizer							

+ See Coding Key, Table 5-1, Chapter 5, page 45, for units for individual effluent properties.

TABLE 15-2 (Concluded)

A. Particulate (Part II)

Source	Solubility	Wettability	Hygroscopic Characteristics	Flammability or Explosive Limits	Handling Characteristics	Optical Properties	Odor
Fertilizer Industry							
1. Phosphate fertilizer							
a. Phosphate rock							
b. Wet-process acid	Contains H_2O soluble components						
c. Superphosphate production							
(1) Acid reactor (den)					Wet silica fluoride flakes are corrosive to materials		
(2) Dryer	Contains H_2O soluble components		Hygroscopic		Corrosive, sticky, agglomerates	Tan-colored dust	
d. Triple superphosphate production	" "						
e. Diammonium phosphate production							

B. Carrier Gas

Source	Flow Rate	Temperature	Pressure	Moisture Content	Chemical Composition	Toxicity	Corrosivity	Odor	Flammability or Explosive Limits	Optical Properties
Fertilizer Industry										
1. Phosphate fertilizer										
a. Phosphate rock										
(1) Rock dryer					CO_2, O_2, N_2, H_2O, SO_2					
(2) Rock grinder										
(3) Roaster or calciner										
Fluid bed roaster	(a) 50	300		Wet bulb temp. 165						
b. Wet-process acid										
(1) Reactor or digestor	(a) 2-16	96-150			Fluorides	Toxic				
(2) Filter	(a) 3.4-19.6	90-95			Fluorides	Toxic				
c. Superphosphate production										
(1) Acid reactor (den)					SiF_4, CO_2, H_2O, SO_x	Toxic	Corrosive			
(2) Granulator-ammoniator					NH_3, SiF_4, HF	Toxic	Corrosive			
(3) Dryer	(a) 16.5 (1 unit)	201			Fluorides, NH_3, SO_x, CO_2, N_2, O_2	Toxic				
(4) Cooler										
d. Triple superphosphate production										
(1) Acid reactor					Fluoride	Toxic				
(2) Granulator					NH_3, fluoride	Toxic				
(3) Dryer					NH_3, fluoride	Toxic				
(4) Cooler					Fluoride	Toxic				
e. Diammonium phosphate production										
(1) Reactor					NH_3					
(2) Ammoniator					NH_3, fluorides	Toxic				
(3) Dryer					NH_3, fluorides	Toxic				
(4) Cooler					NH_3, fluorides	Toxic				

TABLE 15-3

SUMMARY OF EMISSION DATA ON PERFORMANCE OF CONTROL[6] EQUIPMENT IN WET-PROCESS PHOSPHORIC ACID PLANTS[a]

Plant Number	1	2	3	4	5	6	7	8	9	10
Collector type	Rectangular spray chamber	Square horizontal spray duct	Venturi scrubber, water-actuated	Venturi scrubber, water-actuated	Spray cross-flow packed scrubber	Two impingement scrubbers in series	Spray cross-flow packed scrubber	Spray cross-flow packed scrubber	Cyclone spray tower	Spray cross-flow packed scrubber
Gaseous fluoride entering collector per ton of P_2O_5 produced, pound	1.265-2.16	Not determined	0.21-0.31	0.49-0.67	0.078-0.087	0.013-0.016	1.20-1.48	0.05-0.06	0.85-1.00	Not determined
Gaseous fluoride emitted from collector per ton P_2O_5 produced, pound	0.52-0.63	0.072-0.101	0.027-0.047	0.028-0.038	0.006-0.018	0.006-0.011	0.10-0.17	0.0170-0.022	0.047-0.082	0.135-0.157
Collection efficiency, %	57-72		84.2-87.0	92-96	80-92.4	15-62	86-93	56.7-68.4	90.4-95.3	
Concentration of gaseous fluoride emitted from collector, grain/scf	0.075-0.090	0.0026-0.0035	0.0104-0.0147	0.018-0.023	0.0011-0.0032	0.0020-0.0037	0.0054-0.0088	0.0022-0.0029	0.0016-0.0029	0.0120-0.014
Parts per million	202-243	7.0-9.4	28-40	49-62	3.0-8.6	5.4-10.0	15-24	5.9-7.8	4.3-7.8	32-38
Particulate emitted from collector per ton P_2O_5 produced, pound										
Total particulates	0.28-0.50	0.36-0.47	0-0.029							0.29-0.36
Efficiency, %			98.5-100							
Insolube particulate fluorides	0.0006-0.008	0-0.0013	None found							0.006-0.09
Efficiency, %			100							
Soluble particulate fluorides	0.050-0.094	0.0075-0.036	0.0023-0.0029							0.070-0.14
Efficiency, %			94.0-97.0							

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[a] Plants 1-10 were tested by National Air Pollution Control Administration.

TABLE 15-4

SUMMARY OF EMISSION DATA ON PERFORMANCE OF CONTROL EQUIPMENT[6] IN WET-PROCESS PHOSPHORIC ACID PLANTS[a]

Plant Number	11	12	13	14	15	16
Collector type	Venturi scrubber, water-actuated	Cyclonic spray	Spray cross-flow packed scrubber	Spray cross-flow packed scrubber	Impingement	Packed tower, two-stage cyclonic scrubber, in parallel
Gaseous and water-soluble particulate fluoride entering collector per ton of P_2O_5 produced, pound	2.0	7.6	0.53	77	0.037	0.0073
Gaseous and water-soluble particulate fluoride emitted from collector per ton of P_2O_5 produced, pound	0.26	1.23	0.044	0.038	0.0087	0.00035
Efficiency, %	87	84	92	99.9	24	1
Concentration of gaseous and water-soluble particulate fluoride emitted from collector						
Grain/scf	0.058	0.031	0.0032	0.0019		
Parts per million	167	87	9	5		

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a/ Information on plants 11 through 13 acquired through private communication; information on plants 15 and 16 acquired through questionnaire.

15.7.1.2 Acidulation Process - Superphosphate: Acidulation of ground phosphate rock with H_2SO_4 to produce superphosphate results in emissions consisting of silicon tetrafluoride, dilute fluosilicic acid, CO_2, steam, and SO_2.[3] An injector-type gas scrubber was reported to be only 80% efficient for controlling these emissions, allowing H_2SiF_6 and traces of SO_2 and SO_3 as a mist to be discharged into the air.[4] This unit subsequently was replaced by a low-velocity cell type, wet scrubber which was reported to achieve 100% removal of silica fluoride.[4]

Current practice is to scrub gases with either copious quantities of water or with dilute fluosilicic acid. Spray towers, grid-packed towers, and high-velocity jet scrubbers have been used.[3]

15.7.1.3 Triple Superphosphate: Water scrubbers are the primary method for controlling emissions of gaseous fluorides from triple superphosphate production. Packed towers, venturi scrubbers, wet-pad and impingement scrubbers and cyclonic scrubbers have been investigated.[5] A cyclonic scrubber system was reported to eliminate 97% of the total fluorides liberated by all sources in one plant producing triple superphosphate.[5]

15.7.1.4 Granulation: Control of emissions from fertilizer granulation involves collection of dry dust from rotary dryers, rotary coolers, and gas and dust from liquid-solid reactor units. Various high-duty cyclones have been used for removal of dust in exist gases. Efficiencies of 94-96% have been reported in British plants.[3] It is also customary to supplement cyclones by a wet scrubber to further reduce dust content and to remove acid constituents.[5] A multiple-tube collector, operating with 5 in. w.g. pressure drop, has been reported to remove 100% of all dust > 14 μ.[4]

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CHAPTER 16

ASPHALT

16.1 INTRODUCTION

Asphalt is a raw material for several industries. Two of the more important with regard to air pollution are hot-mix asphalt paving plants and asphalt-roofing manufacturing facilities.

The preparation of hot-mix asphalt paving involves proportional feeding of cold aggregates, heating and drying of aggregates to predetermined levels of moisture content and temperature, and uniform mixing and coating with hot asphalt to produce a specific paving mix. After mixing, the hot paving mixture is discharged into trucks which transport it to the paving site. Dust sources are the rotary dryer, hot-aggregate elevator, vibrating screens, hot-aggregate storage bins, weigh hopper, mixer, and transfer points. The major dust source is the rotary dryer.1/

The manufacture of asphalt roofing felts and shingles involves saturating a fiber media with asphalt by means of dipping and/or spraying. While not always done at the same site, an integral part of the operation is the preparation of the asphalt saturant. This preparation consists of oxidizing the asphalt and is accomplished by bubbling air through liquid asphalt for 8-16 hr. This operation is known as "blowing." The principal particulate emission sources are the saturator and blowing operations.

Manufacturing processes, particulate emission sources, particulate emission rates, effluent characteristics, and control practices and equipment for the hot-mix asphalt paving and the asphalt roofing industries are discussed in the following sections.

16.2 AIRBLOWN ASPHALT

Asphalt is a dark brown to black, solid or semi-solid material found in naturally occurring deposits or as a colloidal suspension in crude oil. Analytical methods have been used to separate asphalt into three component groups--asphaltenes, resins, and oils. A particular grade of asphalt may be characterized by the amounts of each group it contains. The asphaltene particle provides a nucleus about which the resin forms a protective coating. The particles are suspended in an oil that is usually paraffinic but can be naphthenic or naphtheno-aromatic.

Over 90% of all asphalt used in the United States is recovered from crude oil (Kirk and Othmer). The method of recovery depends upon the type of crude oil being processed. Practically all types of crudes are first distilled at atmospheric pressure to remove the lower boiling materials such as gasoline, kerosene, diesel oil, and others. Recovery of nondistillable asphalt from selected topped crudes may then be accomplished by vacuum distillation, solvent extraction, or a combination of both.1/ Economical removal of the gas-oil fraction from topped crude, leaving an asphaltic product, is occasionally feasible only by airblowing the crude residue at elevated temperatures. Excellent paving-grade asphalts are produced by this method. Another important application of airblowing is in the production of high-quality specialty asphalts for roofing, pipe coating, and similar uses. These asphalts require certain plastic properties imparted by reacting with air.1/

Airblowing is mainly a dehydrogenation process. Oxygen in the air combines with hydrogen in the oil molecules to form water vapor. The progressive loss of hydrogen results in polymerization or condensation of the asphalt to the desired consistency. Blowing is usually carried out batchwise in horizontal or vertical stills equipped to blanket the charge with steam, but it may also be done continuously. Vertical stills are more efficient because of longer air-asphalt contact time. The asphalt is heated by an internal fire-tube heater or by circulating the charge material through a separate tubestill. A temperature of 300° to 400°F is reached before the airblowing cycle begins. Air quantities used range from 5 to 20 cu ft/min/ton of charge. Little additional heat is then needed since the reaction becomes exothermic. Figure 499 in Reference 1 depicts the flow through a typical batch-type unit.

16.2.1 Effluents and Control Methods

Effluents from the asphalt airblowing stills include oxygen, nitrogen and its compounds, water vapor, sulfur compounds, and hydrocarbons as gases, odors, and aerosols. An estimate of particulate emissions for asphalt blowing associated with asphalt roofing manufacture is given in Table 16-1.

Control of effluent vapors from asphalt airblowing stills has been accomplished by scrubbing and incineration, singly or in combination. Most installations use the combination. Essential to effective incineration is direct-flame contact with the vapors, a minimum retention time of 0.3 sec. in the combustion zone, and maintenance of a minimum combustion-chamber temperature of 1200°F. Other desirable features include turbulent mixing of vapors in the combustion chamber, tangential flame entry, and adequate instrumentation. Primary condensation of any steam or water vapor allows use of smaller incinerators and results in fuel savings. Some of the heat released by incineration of the waste gases may be recovered and used for

TABLE 16-1

PARTICULATE EMISSIONS - ASPHALT

Source	Quantity of Material	Emission Factor	Efficiency of Control (C_c)	Application of Control (C_t)	Net Control ($C_c \cdot C_t$)	Emission (tons/yr)
I. Asphalt Roofing	6,264,000 tons/year (asphalt used in roofing manufacturer)					
A. Blowing		4 lb/ton			0.50	3,000
B. Saturator		4 (controlled)			--	14,000
II. Hot-Mix Paving Plants	251,000,000 tons/year (hot-mix asphalt)					
A. Dryer		32*				
B. Bins, weigh hopper, etc.		8				
		40	0.97	0.99	0.96	201,000
		Total for Primary Users of Asphalt				218,000

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* Prior to any control equipment.

generation of steam. Catalytic fume burners are not recommended for the disposal of vapors from the airblowing of asphalt because the matter entrained in the vapors would quickly clog the catalyst bed.[1]

16.3 HOT-MIX ASPHALT PAVING PLANTS

Generally, a hot-mix asphalt plant consists of a rotary dryer, screening and classifying equipment, an aggregate weighing system, a mixer, storage bins and conveying equipment. Hot-mix plants can be classified according to permanence of location or according to the method of measuring and mixing the hot aggregate and asphalt. Portable plants are designed to be readily dismantled and transported on trailers from one job site to another, whereas permanent (or stationary) plants are set up for efficient operation in a relatively permanent location, usually in a metropolitan area.[3]

With regard to the final mixing process, plants are either of the batch or continuous-mix type. Both types of plants have the same pattern of material flow up to the point of measuring the aggregate from the hot bins into the mixer. In the batch-type plant, the operator weighs out the correct quantity of aggregate from each hot bin in succession into the mixer. The total batch of aggregate is then dry mixed in the pugmill for a prescribed time, during which time the operator proceeds to accumulate another batch in the weigh hopper. When the dry-mix cycle is complete, hot asphalt is added to the mixer by either metering or weighing the correct amount. The hot asphalt may be sprayed or dumped into the pugmill, and upon completion of the proper mixing cycle, the hot-mix asphalt is delivered through a hopper into trucks hauling to the job site. Figure 16-1 shows a typical batch plant and identifies potential sources of air pollutants.[3]

The continuous-mix plant transfers a preblended mixture of the dried and graded aggregate from the gradation unit by means of a bucket elevator to the mixer. Dry mixing in the mixer is not required, as it is in the batch plant. The hot asphalt is sprayed on the aggregate as it falls from the top of the elevator into the mixer. The length of the mixing cycle in a continuous-mix plant is governed by an adjustable dam at the discharge end of the pugmill; the hot-mix asphalt flows over the dam into the discharge hoppers. Mixing time can be varied without changing the hourly tonnage output by varying the height of the adjustable dam. In Figure 16-2 a typical continuous plant is shown with potential sources of pollutants identified.[3]

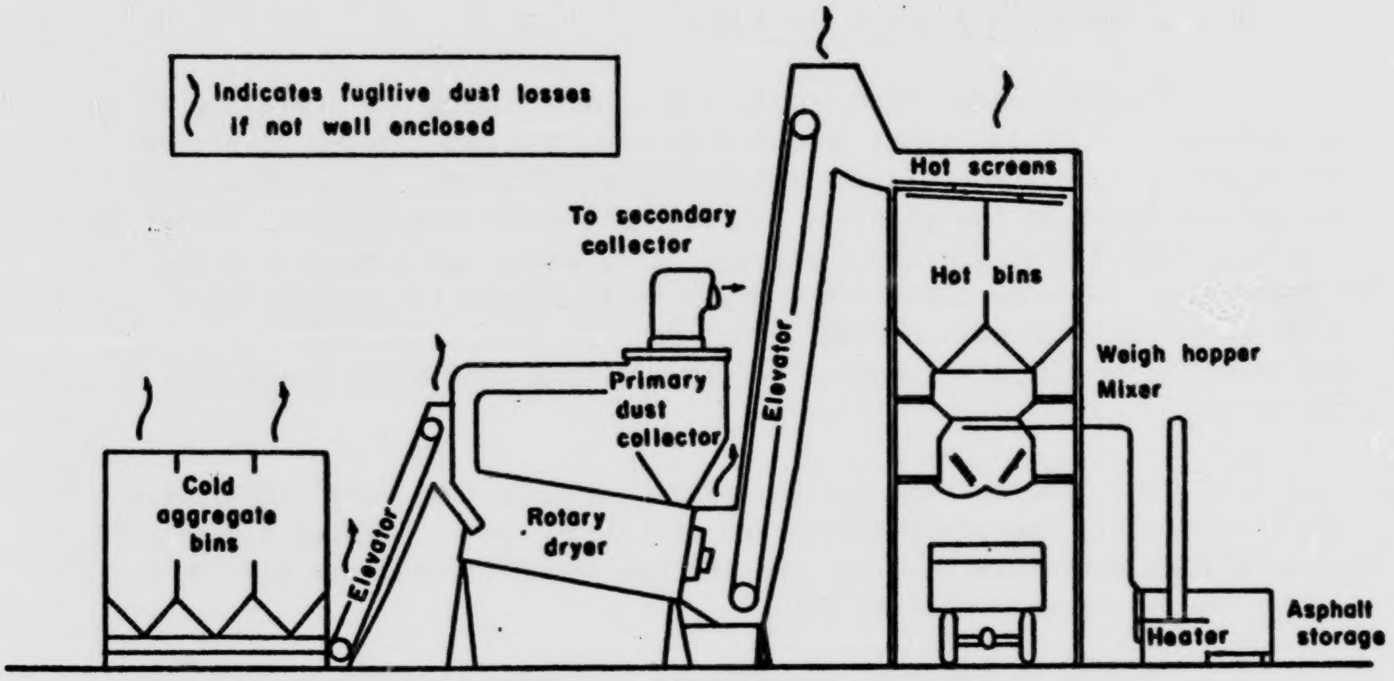

Figure 16-1 - Asphalt Batch Mix Plant[3]

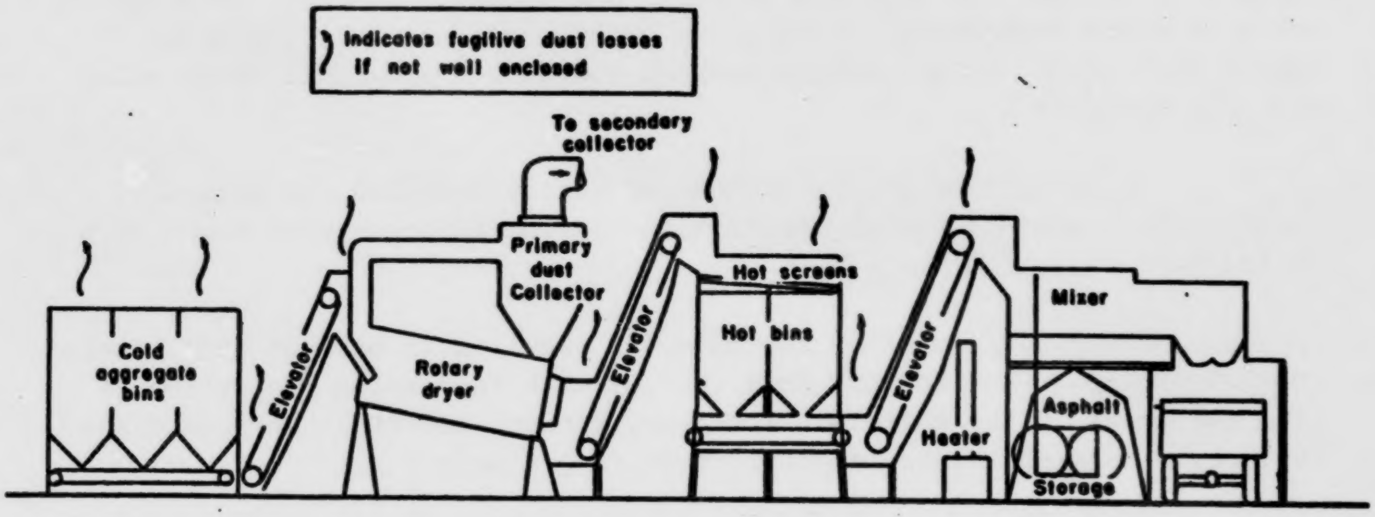

Figure 16-2 - Asphalt Continuous Mix Plant[3]

16.3.1 Emission Sources and Rates

Pollutants released to the atmosphere during the operation of a hot-mix asphalt paving plant are both particulate and gaseous in nature. The major source of dust is the rotary dryer. However, while dust from the rotary dryer is the greatest source, dust collected from the vibrating screens, the bucket elevator, storage bins, and weigh hopper is also significant. In some plants, the dryer dust problem is handled separately from the other sources. However, the trend is to combine both the dryer and ventline or fugitive sources together with a single collector fan system.

Dust loadings and particle-size distribution vary widely from plant to plant. The dryer design and operation, particle-size distribution of feed materials, and the specific grade of asphalt mix will have a very marked effect on emissions.

Studies in the Los Angeles area indicated that stack emissions increase linearly with an increase in the amount of -200 mesh material processed and that emissions were higher when the dryer was oil-fired rather than gas-fired.4/

A study conducted in Germany provided extensive test data on the influence of feed composition, plant size, and control techniques on emissions.10/ The quantity and particle size of dust in the waste gases from the drum dryer was found to extend through a wide range and to depend largely on whether the starting material was washed, unwashed, or processed in mixed components. Completely washed raw material caused the lowest dust load. Values ranged between 9.7-17.2 grains/scf. Mean value was 13.2 grains/scf.

In processing partly washed and partly unwashed raw material, dust contents measured during production of fine concrete were about 30.8 grains/scf.

Processing unwashed raw material resulted in maximum dust levels in waste gases. Dust content rose sharply with increasing proportion of fine particles in the materials for base, binder, and fine concrete manufacture. Measured values ranged from 19-72 grains/scf.10/

Table 16-1 summarizes emission levels from hot-mix asphalt paving plants. Currently paving plants emit about 200,000 tons/year of particulate matter.

16.3.2 Characteristics of Hot-Mix Asphalt Plant Effluents

The chemical and physical properties of hot-mix asphalt plant effluents are summarized in Table 16-2. Particulate pollutants involved in asphalt plant operations include stone dust, fly ash, soot, and unburned droplets of fuel oil. Stone dust is caused by the release of dust from the surface of the larger aggregate particles due to the heat and vibration of the dryer and other components of the plant and to some extent to the fracture of aggregate during the drying and screening processes.

Particulates emitted from the dryer have a highly variable particle size and may range from 10-90 wt. % $< 10\ \mu$.

16.3.3 Control Practice and Equipment for Hot-Mix Asphalt Plants

Total ventilation requirements for the rotary dryer and the secondary dust sources vary according to the size of plant. For a 6,000 lb/batch plant, 22,000 scfm is typical, of which ~ 3,000 scfm is required for the secondary sources. Table 16-3 and Figure 16-3 illustrate test data on air pollution equipment serving two hot-mix asphalt paving plants.1/

A typical asphalt plant dryer effluent will contain 20-30 grains/cu ft.5/ However, the loading can vary widely as shown in the table of effluent characteristics. Test data for some Florida asphalt plants are given in Table 16-4.6/

The dust carried out of the dryer into the dust collection system increases rapidly with a rise in drum gas velocity. Figure 16-4 shows the effect of increasing drum gas velocity on the dust carry-out for a typical aggregate.3/

16.3.3.1 Cyclones: The collection of asphalt plant dusts is usually by means of cyclones for the primary dust collection followed by a higher efficiency type of secondary collector. One recently installed control system consisting of cyclones followed by low-pressure drop wet scrubbers is reported to attain 99.89% overall collection efficiency.7/ Measurements of cyclone-scrubber systems on 14 asphalt plant dryers showed > 98.0% efficiency.9/ Comparative cost data are presented in Table 16-5.3/ The ranges shown for installed cost and power consumption are in good agreement with general cost curves and equations presented in Appendix A. Therefore, these curves could be used for a more accurate estimate of costs if the total gas flow is known.

16.3.3.2 Electrostatic Precipitators: Electrostatic precipitation units do not find much application to asphalt plants since they have a rather high first cost.3/

TABLE 16-2

EFFLUENT CHARACTERISTICS - ASPHALT+

A. **Particulate**

Source	Particle Size	Solids Loading	Chemical Composition	Particle Density	Electrical Resistivity	Moisture Content	Toxicity
I. Hot-Mix Asphalt Batch Plants							
1. Rotary Dryer	Highly variable, extreme range: 13-91 < 10, 32-99 < 20, 55-100 < 44 Bahco Analysis: (2 samples) 19-24 < 5; avg. 22 < 5 30-44 < 10; avg. 36 < 10 45-60 < 20; avg. 53 < 20 64-75 < 40; avg. 69 < 40	Extreme range: 11-200 Typical range: 20-70 Avg.: 30	Stone dust, fly ash, soot, and unburned droplets of oil	2.6 (avg. value)			N.T.
2. Vent Line (Fugitive Sources)	39-46 < 10, 61-87 < 20, 86-99 < 44	23-82; avg.: 53					
II. Asphalt Roofing Manufacture							
1. Saturator		0.42-0.77	Hydrocarbon or oil mist				

B. **Carrier Gas**

Source	Flow Rate	Temperature	Moisture Content	Chemical Composition	Toxicity	Corrosivity	Odor	Flammability or Explosive Limits	Optical Properties
I. Hot-Mix Asphalt Batch Plants									
1. Rotary Dryer	(a) 7.7-46 Avg.: 20 (b) 3.9-24.6 Avg.: 9	85-525 Avg.: 240	Dew point 140-160	CO_2, NO_x, N_2, O_2, CO	CO - 100				
2. Vent Line	(a) 2.8-3.7	200-215							
II. Asphalt Roofing Manufacture									
1. Saturator	(a) 10-20	135-217	2.7-6.4						50% opacity over saturator tank

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+ See Coding Key, Table 5-1, Chapter 5, page 45, for units for individual effluent properties.

TABLE 16-3

DUST AND FUME DISCHARGE FROM ASPHALT BATCH PLANTS [1]

Test No.	C-426		C-537	
Batch Plant Data				
Mixer capacity, lb.	6,000		6,000	
Process weight, lb/hr**	364,000		346,000	
Dryer Fuel	Oil, PS 300		Oil, PS 300	
Type of mix	City street, surface		Highway, surface	
Aggregate feed to drier				
+ 10 mesh, wt. %	70.8		68.1	
- 10 to + 100 mesh	24.7		28.9	
- 100 to + 200 mesh	1.7		1.4	
- 200 mesh	2.8		1.6	
Dust and Fume Data	Vent Line*	Dryer	Vent Line*	Dryer
Gas volume, scfm	2,800	21,000	3,715	22,050
Gas temperature, °F	215	180	200	430
Dust loading, lb/hr	2,000	6,700	742	4,721
Dust loading, grain/scf	81.8	37.2	23.3	24.98
Sieve analysis of dust				
+ 100 mesh, wt. %	4.3	17.0	0.5	18.9
- 100 to + 200 mesh	6.5	25.2	4.6	32.2
- 200 mesh	89.2	57.8	94.9	48.9
Particle size of - 200 mesh				
0 - 5 microns, wt. %	19.3	10.1	18.8	9.2
5 - 10 microns, wt. %	20.4	11.0	27.6	12.3
10 - 20 microns, wt. %	21.0	11.0	40.4	22.7
20 - 50 microns, wt. %	25.1	21.4	12.1	49.3
> 50 microns, wt. %	14.2	46.5	1.1	6.5

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* Vent line serves hot elevator, screens, bin, weigh hopper and mixer.

** "Process weight"--a process weight definition is given in Rule 2 j, of the Rules and Regulations of the Los Angeles County Air Pollution Control District.

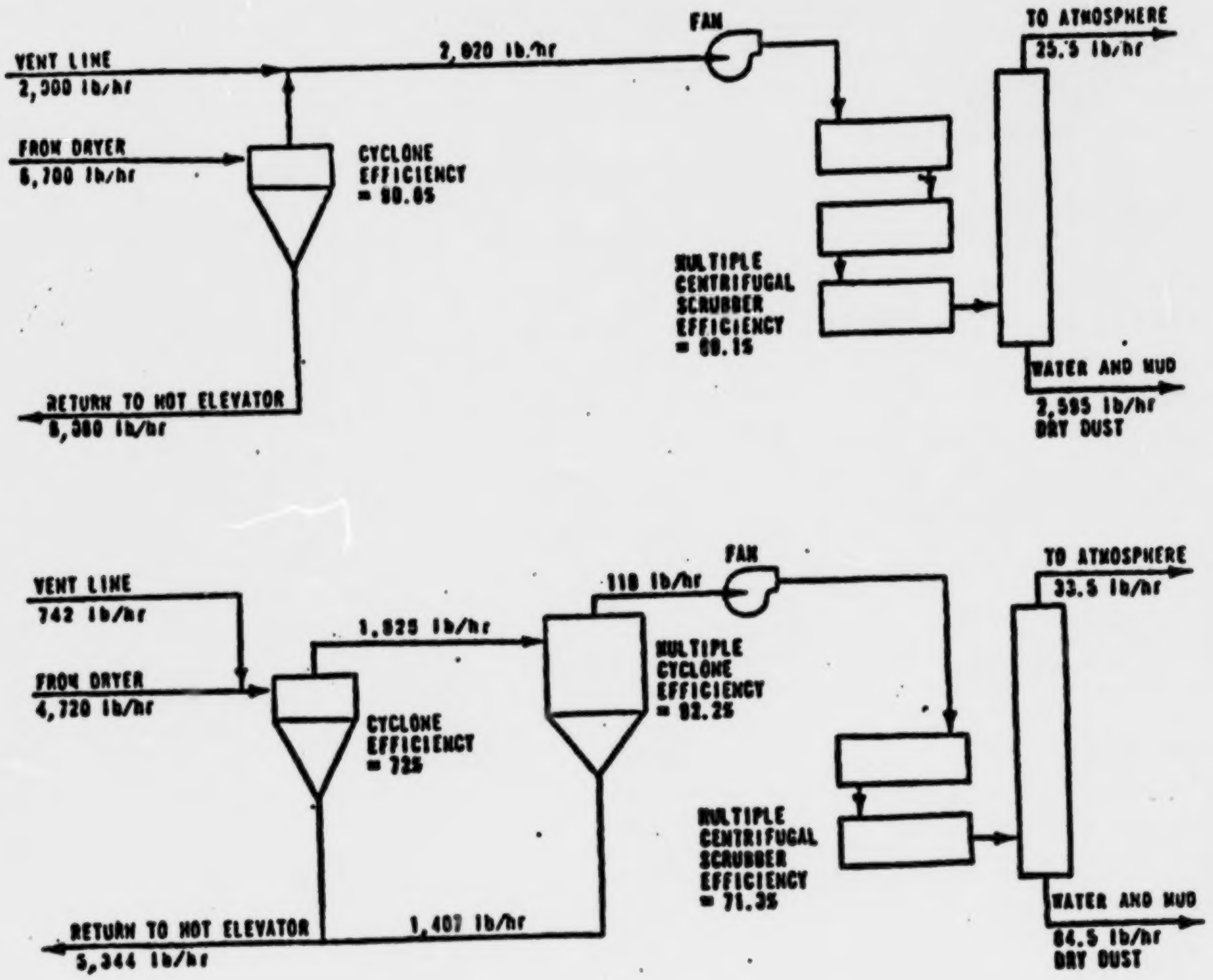

Figure 16-3 - Test Data on Air Pollution Control Equipment Serving Two Hot-Mix Asphalt Paving Plants (Vent Line Serves Screens, Hot Bins, Weigh Hopper, and Mixer)[1]

TABLE 16-4

FINDINGS OF FLORIDA ASPHALT PLANT TESTING PROGRAM 6/

Name of Asphalt Plant	Production (tph)	Before Cyclone		After Cyclone		Scrubber Outlet	
		(gr/cu ft)	(lb/hr)	(gr/cu ft)	(lb/hr)	(gr/cu ft)	(lb/hr)
1. Houdaille Duval Asphalt Plant	96	-	-	0.51	240	-	-
2. Basic Asphalt	90	-	-	-	-	2.30	509
3. (a) Jaxon Const. Co.	120	21.2	6,830	5.42	1,883	0.765	205
(b) Jaxon Const. Co.	-	-	-	-	-	0.433	116
4. Florida Four Const. Co.	-	33.7	12,000	15.2	3,120	-	-
				14.3	2,930		
5. Dunn Const. Co.	99	-	-	-	-	0.370	54.0
						0.301	43.9
						0.283	41.4
6. Mac Asphalt	200	-	-	-	-	0.229	26.8
						0.349	40.6
7. Florida Hot Mix	120	-	-	9.47	1,020	0.135	25.7
				5.73	620	0.227	43.2
8. Rubin Const.	140	-	-	-	-	0.279	8.34
						0.297	8.15
						0.311	8.55

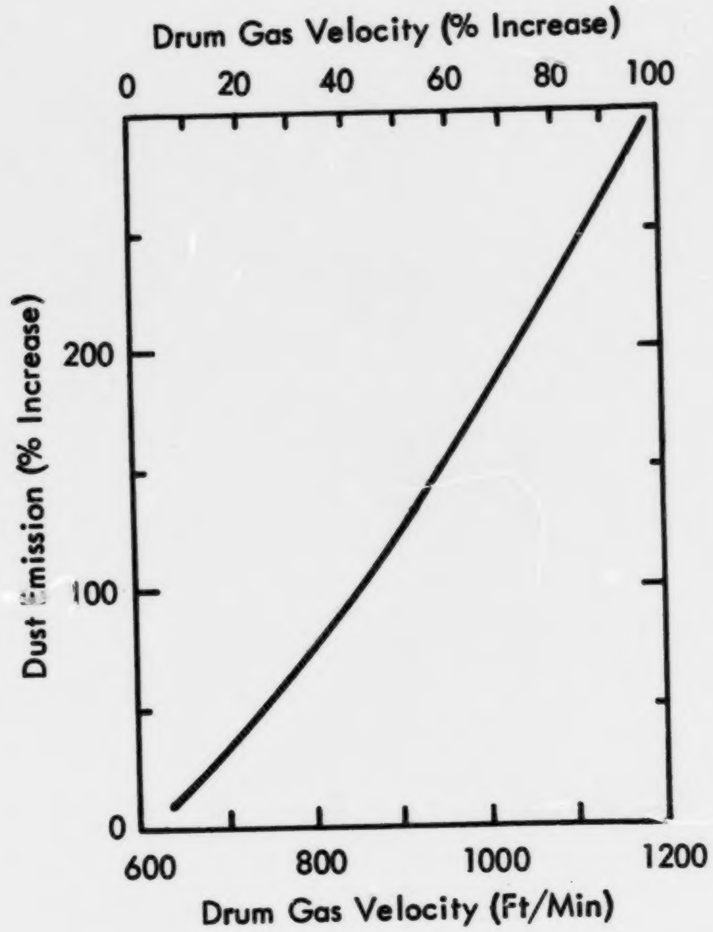

Figure 16-4 - Effect of Drum Gas Velocity on Dust Emission[3]

TABLE 16-5

COMPARATIVE COSTS OF DUST COLLECTORS [3]

Type	Installed Cost ($/cfm)	Power Consumption (kw/1,000 cfm)	Pressure Drop (in. water)
Primary			
Settling chamber	0.1	0.1	0.1 - 0.5
Cyclone, large dia.	0.1 - 0.2	0.1 - 0.5	0.5 - 3.0
Cyclone, medium dia.	0.2 - 0.3	0.3 - 0.8	1.0 - 4.0
Secondary			
Cyclone, multiple	0.3 - 0.6	0.5 - 2.0	2.0 - 10.0
Filter, cloth tubular	0.3 - 2.0	0.5 - 1.5	2.0 - 6.0
Precipitator, electric	0.6 - 3.0	0.2 - 0.6	0.1 - 0.5
Scrubber, spray tower	0.1 - 0.2	0.1 - 0.2	0.1 - 0.5
Scrubber, wet cyclone	0.3 - 1.0	0.6 - 2.0	2.0 - 8.0
Scrubber, packed tower	0.3 - 0.6	0.6 - 2.0	0.5 - 10.0

16.3.3.3 Fabric Filters: Fabric filters provide excellent collection of fine particles with little or no visible emissions. Although fabric filters frequently are more expensive than wet scrubbers, they collect dry "fines" which may be usable in high-grade asphaltic concrete mixes. In addition, they obviate the need for holding ponds and preclude water problems.[2]

Filters are subject to operating difficulties when installed in an intermittent process such as asphalt dryers.[5] Precautions must be taken to prevent overheating and to prevent condensation during shutdowns.

The air-to-cloth ratios for fabric filters will vary from 3.5:1 to 6.25:1. Reverse air supply is normally heated, and the collector housing insulated, to prevent condensation.[8]

16.3.3.4 Wet Collectors: Wet collectors are in wide use in the asphalt paving industry and generally give good results without serious maintenance problems. The scrubbing liquid from these collectors requires a settling pond of adequate size. This pond should be at least 6 ft. deep and hold at least 2 hr. discharge of the scrubber. The sludge collected in the pond must be pumped or dredged out and removed to an appropriate disposal area avoiding any chances for stream pollution.[3]

The effect of scrubber water/gas ratio on stack emissions is a very important factor as shown in Figure 16-5.[4] The best utilization of water is achieved up to a ratio of 6 gal/1,000 scf of gas. Above this ratio, efficiency still increases but at a lesser rate as illustrated in Figure 16-5.

16.4 ASPHALT ROOFING MANUFACTURE

Asphalt-saturated felt is manufactured in high-speed, continuously operating machines, referred to as asphalt saturators. An integral part of the operation is the preparation of the asphalt saturant. This preparation consists of oxidizing the asphalt and is accomplished by bubbling air through liquid (450-500°F) asphalt for 8 to 16 hr. The industry refers to this operation as "blowing." The time required for blowing depends on the desired properties of the saturant. It had been the practice to blow the asphalt in horizontal stills where the material loss ranges from 3 to 5%.[11] Most of this material is recovered by venting the exhaust gases through oil knock-out tanks which are an integral part of the process. The recaptured mist is not reintroduced into the saturant but is used for other products such as cut-back asphalt. Thus, in horizontal stills, it requires ~ 1.05 tons of asphalt to produce 1.00 ton of saturant. However, most roofing manufacturing firms are currently using vertical stills from which the material loss is 1 to 2% over a 1-1/2 to 5 hr. cycle.[11]

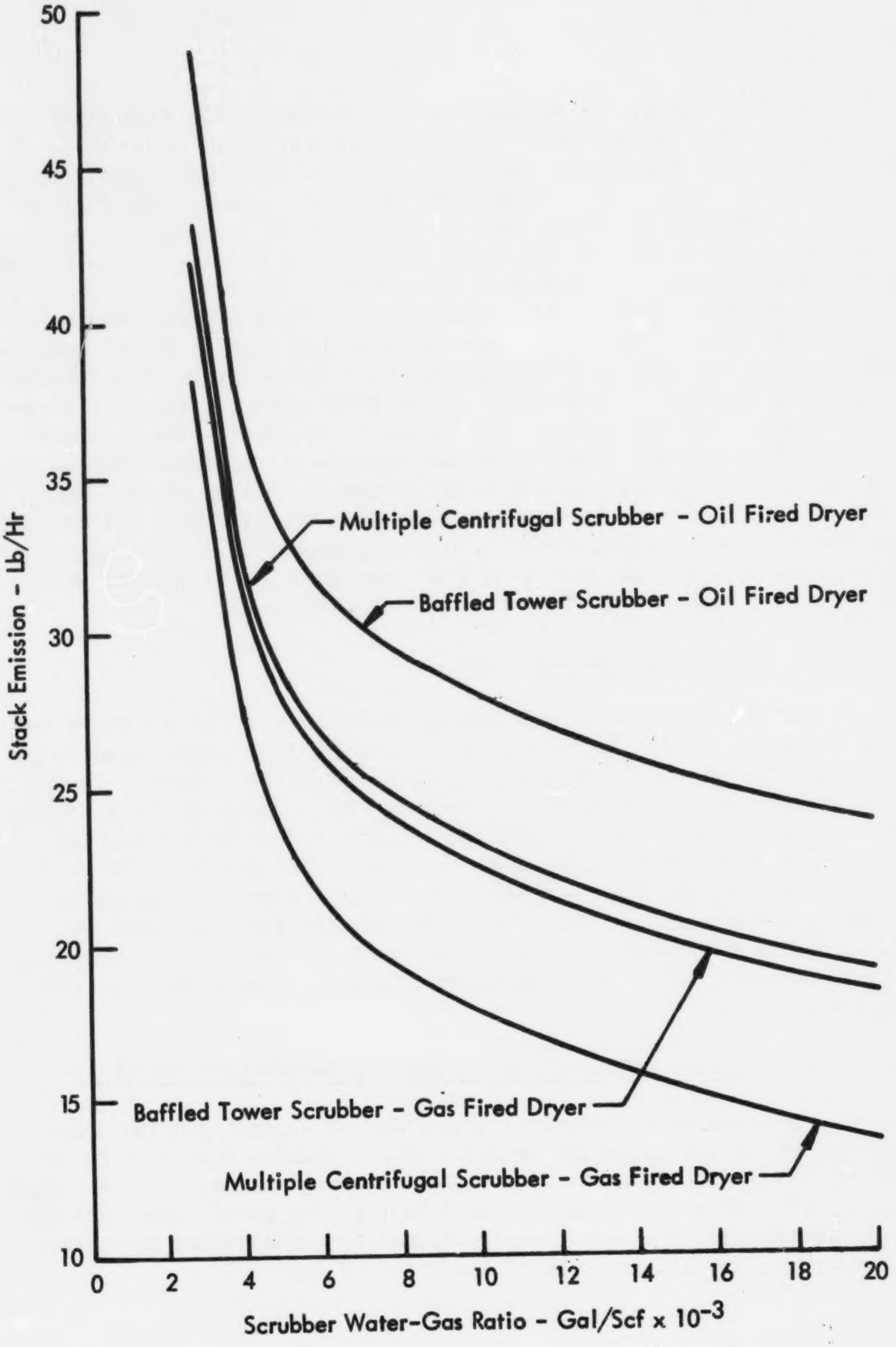

Figure 16-5 - Effect of Scrubber Water-Gas Ratio on Stack Emissions[4/] at Average Aggregate Fired Rate in the Dryer Feed

After blowing, the saturant is transported to the saturation tank or spray area. Figure 16-6 is a schematic drawing of an asphalt roofing saturator. The asphalt saturator consists of a dry looper, an asphalt spray section, a saturating tank, and a wet looper. The felt is continuously fed from rolls into the dry looper where it is arranged over rollers into a series of vertical loops used as live storage in the process to permit maintenance of feed at a uniform rate to the saturating process during roll changes. The liquid asphalt at 400°F to 450°F may then be sprayed on one side of the felt. This spray of hot asphalt drives moisture in the felt out the unsprayed side and prevents the moisture from forming blisters when the felt is saturated. After being sprayed, the felt passes through a tank of molten asphalt that saturates the felt. The saturated felt then enters the wet looper where the material is arranged over another set of rollers into long, vertical loops to permit cooling of the asphalt. The web of saturated felt is then rolled up from the discharge end of the wet looper for use as roofing felt or building paper, or a small quantity of bituminous material and mica schist or rock granules is applied to the surface to make composition roofing paper and shingles.1/

16.4.1 Emission Sources and Rates

The main sources of particulate emissions are the saturator and "blowing" stills. The relatively high application temperature results in the vaporization of the lower boiling components of the asphalt. Vaporization of moisture in the felt also occurs. These vaporization processes produce a highly opaque mist. Additional vapors and mists are emitted from the saturated felt in the wet looper. The mass emission rate is a function of felt feed rate, felt moisture content, number of sprays used, and asphalt temperature.1/ Table 16-1 presents the emission rates for asphalt roofing manufacture. Limited test data are available on emission rates, and emission totals for roofing manufacture in Table 16-1 are conservative estimates.

16.4.2 Characteristics of Asphalt Roofing Manufacture Emissions

The chemical and physical properties of asphalt roofing manufacture effluents are presented in Table 16-2. Limited data were found on the properties of effluents from asphalt roofing manufacture. Although no quantitative data were found on particle size for particulates emitted from the saturators, the particles are formed by condensation processes, and, therefore, are likely to be of the order of 1 μ.

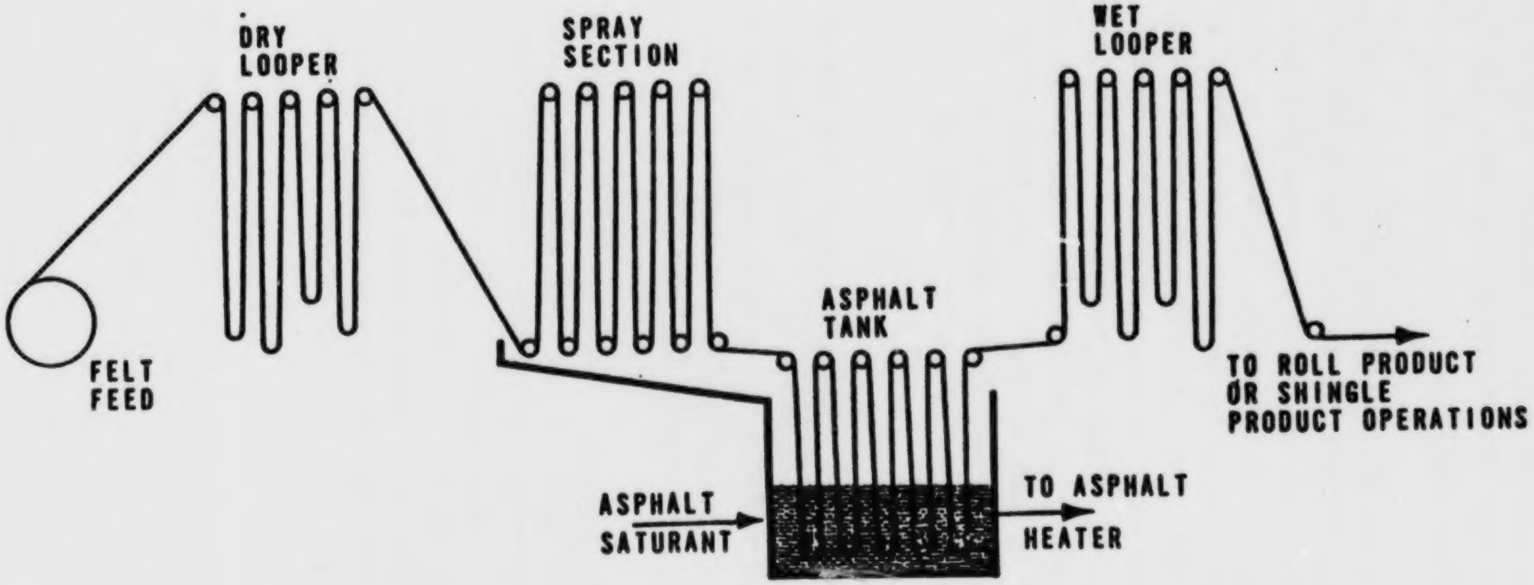

Figure 16-6 - Schematic Drawing of an Asphalt Roofing Felt Saturator[1]

16.4.3 Control Practices and Equipment for Asphalt Roofing Manufacture

Common methods of air pollution control at asphalt saturating plants include complete enclosure of the spray area and saturator followed by good ventilation through one or more collection devices including combinations of wet scrubbers, and two-stage low-voltage electrical precipitators, or cyclones and fabric filters.

Hoods for collecting the emissions should be installed so that there is a single continuous enclosure around the points of emission, extending down to the floor. Since operating personnel must have access to the saturator for operating adjustments, doorways or other provisions for entrance in the hood must usually be supplied. These should be kept as small as possible. In addition, openings in the hoods must be provided for the entrance of felt and exit of the saturated material. These openings should be as close to the floor as possible. Experience indicates that a minimum indraft velocity of 200 fpm is required at all hood openings. Air volumes handled by the exhaust system vary with hood design and saturator size but are about 10,000 to 20,000 scfm. The large volume of air required in controlling the saturator equipment generally makes incineration impractical.

16.4.3.1 Electrostatic Precipitators: The low-voltage, or two-stage, electrical precipitator preceded by a spray scrubber as a pre-cleaner gives relatively high collection efficiency as well as substantial reduction in the opacity of the saturator effluent. Table 16-6 shows the test results on a scrubber precleaner followed by a two-stage precipitator.1/

16.4.3.2 Fabric Filters: Baghouse filters are occasionally used as air pollution control devices for asphalt saturators, but their use is limited as a result of maintenance problems associated with filter bag upkeep and their high power requirement. Oil collected by the filter fabric is oxidized and polymerized by the air stream, causing plugging of the fabric and increasing the pressure drop across the filter unit. The air volume handled by the exhaust system then decreases because of increased pressure drop and results in loss of mist capture at the saturator's hood openings.

16.4.3.3 Scrubbers: Spray-type scrubbers have met with limited success as air pollution control devices for saturators. Some spray scrubbers may have an efficiency, based on weight removed, as high as 90%, but the scrubber's effluent may be from 50 to 100% opaque. This opaque discharge is due to the extremely low collection efficiency of spray scrubbers for particles < 1 μ in diameter. These small-diameter particles, when emitted from the scrubber discharge, cause maximum light scattering and, therefore, high opacities. Table 16-7 shows the results of tests made on a scrubbing system venting an asphalt saturator.1/

TABLE 16-6[1]

EMISSIONS FROM A WATER SCRUBBER AND LOW-VOLTAGE TWO-STAGE ELECTRICAL PRECIPITATOR VENTING AN ASPHALT SATURATOR[1]

	Scrubber Inlet	Precipitator Inlet	Precipitator Outlet
Volume, scfm	20,000	20,234	20,116
Temperature, °F	139	85	82
Emission rate,			
grains/scf	0.416	0.115	0.058
lb/hr	71.4	20	10
Water vapor, percent	3.7	4.9	4.8
Collection efficiency	Scrubber, 71%	Precipitator, 50%	Overall, 86%

TABLE 16-7[1]

EMISSIONS FROM A WATER SCRUBBER VENTING AN ASPHALT SATURATOR[a]

	Scrubber Inlet	Scrubber Discharge
Volume, scfm	12,000	12,196
Temperature, °F	138	82
Emission rate,		
grains/scf	0.535	0.0737
lb/hr	55	7.7
Water, percent	2.7	4.2[a]
Collection efficiency, percent		86

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[a] At 3.7 volume % of water, vapor is saturated air. Other qualitative tests run simultaneously showed no particulate water.

Theoretical evidence indicates that Venturi-type scrubbers remove contaminants with particle sizes of $< 1 \mu$ in diameter, but the initial equipment cost and high energy requirements of the Venturi scrubber make its use economically unattractive compared with other forms of air pollution control equipment.[1] However, such devices may be necessary if high efficiency collection is required to comply with air pollution regulations.

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CHAPTER 17

FERROALLOY MANUFACTURE

17.1 INTRODUCTION

Ferroalloys are used for deoxidation, alloying, and graphitization of steel. In the nonferrous metal industry, silicon is used primarily as an alloying agent for copper, aluminum, magnesium, and nickel. Ferrosilicon, in the form of 75% ferrosilicon, is used as a reducing agent in the production of magnesium by the Pidgeon process.[2/] Manganese is the most widely used element in ferroalloys, followed by silicon, chromium, and phosphorus. Others include molybdenum, tungsten, titanium, zirconium, vanadium, boron, and columbium.

The production of ferroalloys has many dust or fume producing steps. Materials-handling operations and crushing and grinding generate coarse dust, while the pyrometallurgical steps release metallic fumes. The manufacturing process, particulate emission sources, emission rates of individual sources, chemical and physical properties of effluents, control practices, and control equipment are discussed in the following sections.

17.2 FERROALLOY PRODUCTION

There are four major methods used to produce ferroalloy and high-purity metallic additives for steelmaking. These are (1) blast furnace, (2) electric smelting furnace, (3) alumino silico-thermic process and (4) electrolytic deposition. The choice of process is dependent upon the alloy produced and the availability of furnaces. Ferromanganese is the principal metallurgical form of manganese. This product contains 80% or more of manganese, the balance being mainly iron. It is produced in the blast furnace or electric-arc furnace and is available in several grades. A few steel companies produce ferromanganese for their own use since they have their own ore sources and suitable blast furnaces available.

The coke-burning blast furnace, even with high blast temperature (1800 to 2000°F), is not a completely efficient smelter for ferroalloys of manganese, chrome and silicon since the waste slags are relatively high in unreduced Mn and Cr oxides, and not much more than 20% silicon can be reduced economically. This is due to the limitation of temperature generation at the tuyere plane.

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The submerged arc, or the roofed-in open bath electric smelter with intense heat zones (4000 to 5000°F) near the arc can more effectively complete the reduction of the oxides; hence, higher overall yields of the various metallic components and with more general flexibility and control over the operation than is possible in the coke blast furnace. For these reasons the electric furnace is more often used for the production of ferroalloys.

Metallic silicon and aluminum are intense deoxidizers and are often used as reducing agents in the so-called metallothermic reduction processes for ferromolybdenum, ferrovanadium, ferrotitanium, a combination of carbon and aluminum as reductant for ferrozirconium, and the aluminothermic reduction of ferrocolumbium.

Since the reduction of oxides by silicon, and particularly aluminum metal, is exothermic, quite often enough heat is given off by the reaction, so that the ferroalloys can sometimes be smelted outside the furnace.

The pure metals of manganese, nickel, copper and chromium, etc., are most often produced by electrofinning via the electrolytic bath. In the case of manganese, for example, the ores are calcined and leached, usually to form $MnSO_4$, mixed with ammonium salts and delivered in solution to bath. The pure manganese collects as a film about 1/8 in. thick on the cathode, is removed, melted and cast to ingots of 99.7-99.9% Mn.

The blast furnace and electric smelting furnace production method are the major sources of air pollution, and these methods are discussed in more detail in the following paragraphs.

17.2.1 Ferromanganese Blast Furnaces

Ferroalloys are produced in the blast furnace by carbon reduction of manganese ore and iron ore in the presence of coke and limestone. Ferromanganese blast furnaces are usually smaller than pig-iron furnaces and the hot-blast temperatures are lower, approximately 1100-1200°F. The ferromanganese furnaces are blown at a much slower rate and therefore operate without hanging or slipping. Because of the freedom from these mechanical troubles, the shape of ferromanganese furnaces has not been given the same consideration as that of a pig-iron furnace. Oxygen enrichment of the blast has been tried on a commercial scale with a marked increase in furnace capacity.1/

There are no rigid specifications for ores used for producing ferromanganese. The use of a particular ore depends on its cost and grade in comparison with other ores available at a specific point. A mixture of a number of different ores is generally charged to the blast furnace, and they are so proportioned as to meet definite specifications for the final alloy composition. Blending a number of ores improves the physical character of the charge. Low-silica ores are preferred since the volume of slag increases with increased silica in the charge, causing losses in manganese, increased fuel consumption, and loss of tonnage.

The physical structure of the ore is important to economical blast furnace operation. Dust losses are curtailed by mixing hard, coarse ores with fine ores. Although some of the dust is recovered from the flue gases and recharged into the furnace as briquets, there is always a loss of manganese due to the deposition of dust in stoves and boilers.

The physical character of the ore is important with relation to resistance to gas flow. Although large amounts of coarse coke tend to form porous columns offering little resistance to gas flow, fine ore particles do not, which makes it difficult to get a uniform distribution of gas throughout the charge. Nonuniform gas distribution interferes with furnace efficiency as it affects the heat exchange between solid and gas. In pig-iron furnaces, the limit of capacity is reached when the air pressure is so high that it interferes with the settling of the charge, but in ferromanganese furnaces, the loss of manganese by volatilization is what limits the capacity.

Low blast pressure characterizes the operation of a ferromanganese blast furnace. The silicon is easily controlled and no problem is presented by sulfur. Low fuel consumption and the maximum manganese recovery in the metal are the chief operating goals. High manganese recovery is favored by (1) small slag volume, (2) a basic slag, (3) high blast temperatures, and (4) coarse ores.

Although a large amount of fuel is used, the temperatures of ferromanganese furnaces are lower than those of pig-iron furnaces. Several factors are influential in causing this lower temperature. The reducing reaction between MnO and solid carbon or CO is highly endothermic, and since the slag is formed at a comparatively low temperature and is fluid just above its melting point, it carries a relatively small amount of heat down into the furnace crucible. A chilling effect is caused by the large thermal head between the relatively cold slag and the tuyeres in this zone. The result is that the slag reaches the combustion zone at a low temperature. Since the region below the tuyeres depends chiefly on the slag and metal for its supply of heat, this means comparatively low temperatures in the crucible. The low free-running temperature of the ferromanganese slag is not conducive to the high-temperature needs for the reduction of manganese oxide, and a longer time is required. The requisite time interval is accomplished by bringing fresh slag into the crucible at a lower rate; the low blast pressure effects this.

17.2.2 Electric-Arc Furnaces

The majority of ferroalloy furnaces are termed submerged arc, although the mode of energy release in many cases is resistive heating.[2] Raw ore, coke, and limestone or dolomite mixed in proper proportions constitute the charge for the electric-arc furnace process. A large supply of electric power is necessary for economical operation. Important operating considerations include power and electrode requirements, size and type of furnace, amount and size of coke, and the nature of slag losses.

Submerged-arc furnaces generally operate with continuous power except for periods of power interruption or mechanical breakdown of components. Operating times average 90 to 98%. The electrodes operate 3 to 6 ft. above the hearth, and are submerged 3 to 5 ft. below the mix level so that some heat exchange and mass transfer can occur between the reaction gas and the mix. The products produced in this type furnace are chiefly:[2]

1. Silicon Alloys - Ferrosilicon (50 to 98% Si) and CaSi

2. Chromium Alloys - High carbon FeCr in various grades and FeCrSi

3. Manganese Alloys - Standard FeMn and SiMn

There are a smaller number of furnaces which do not operate with deep submergence of the electrodes and produce a batch melt which is usually removed by tilting the furnace. Mix additions and power input would usually be cyclic. Examples of products produced in this type of furnace are:

1. Manganese Ore - Lime melt for subsequent ladle reaction with silicomanganese to produce medium carbon and low carbon ferromanganese

2. Chrome Ore - Lime melt for subsequent ladle reaction with ferrochrom-silicon to produce low carbon ferrochrome

3. Special Alloys, such as Aluminum - Vanadium, Ferrocolumbium

17.3 EMISSION SOURCES AND RATES

The production of ferroalloys has many dust or fume producing steps. Particulates are emitted from raw material handling, mix delivery, crushing, grinding, and sizing, and furnace operations. The dust resulting from the solids-handling steps does not present a difficult control problem. Emissions from furnaces vary widely in type and quantity, depending upon the particular ferroalloy being produced, type of furnace used, and the amount of carbon in the alloy.

In the operation of a blast furnace, a large quantity of dense fume may be emitted to the atmosphere. The amount and types of particles which make up this fume are different from those commonly found in the gases from blast furnaces producing basic pig iron.[3] One type, comprising about 20% of the dust present, consists of particles above 20 μ in size, which appear to originate in the disintegration of coke and ore in the furnace burden. The other type, which accounts for 80% of the solids present in the gas, is a typical fume varying in size from 0.1 to 1.0 μ. This material is formed by a process of vaporization and condensation. Particulate emissions can be reduced by raw materials choice and sound operating practices.

The conventional submerged-arc furnace utilizes carbon reduction of metallic oxides and continuously produces large quantities of carbon monoxide.[1] Other sources of gas are moisture in the charge materials, reducing agent volatile matter, thermal decomposition products of the raw ore, and intermediate products of reaction. The carbon monoxide normally accounts for about 70 vol. % of the gases. The gases rising out the top of the furnace carry fume or fume precursors and also entrain the finer size constituents of the mix or charge. Submerged-arc furnaces operate in steady-state and gas generation is continuous.[2]

In an open furnace, all the CO burns with induced air at the top of the charge, resulting in a large volume of gas. In a closed furnace most or all of the CO is withdrawn from the furnace without combustion with air.

Fume emission also occurs at furnace tap holes. Because most furnaces are tapped intermittently, tap hole fumes occur only about 10 to 20% of the furnace operating time. Another source of fume occurs in handling the metal after the tapping step. Conveying the ladle, pouring, and casting give rise to fumes on an intermittent basis.[2]

Some processes conduct additional reactions in the ladle, such as chlorination, oxidation, and slag-metal reactions. In these cases, there may be actual gas generation in addition to the treatment gas, and possibly gross ejection of a portion of the ladle contents. These are batch processes with intermittent fume generation.[2]

Melting operations may be conducted in an open arc furnace in some plants. While no major quantities of gas are generated in this operation, thermally induced air flow may result in fume emission.[2]

A minor source of particulate pollution on furnaces with self-baking electrodes is the fume resulting from the electrode paste during heating and baking. This fume is usually directly vented.[2]

Emissions and emission rates will vary with (1) type of alloy produced, (2) process (i.e., continuous or batch), (3) choice of raw materials, (4) operating techniques, and (5) maintenance practices.

With silicon alloys, as the percentage of silicon in the alloy increases, the loss of SiO_2 increases, so that a silicon metal furnace produces substantially more fume than a 50% FeSi furnace at the same load.2/ In addition, the higher ferrosilicon operations (75% Si and above) are known as "hot" operations; i.e., the gas exiting from the mix is at a high temperature and the furnace is subject to blows (frequently jets of gas issue at high velocity directly from the high temperature reaction zone). Higher silicon operations are also subject to hearth build-ups of silicon carbide. Under these conditions, electrodes operate in a higher position and more fume can result.2/

Because manganese ores contain a significant amount of water, as well as higher manganese oxides which release oxygen upon heating at temperatures below 1000°C, a manganese furnace can be subject to "rough" operation. Sudden release of gas can result in substantial mix ejection from the furnace. In furnaces with self-baking electrodes, the relatively oxidizing atmosphere can result in "fluting" of the electrodes, furnishing a direct gas passage from the high temperature zone of the furnace, with increased fume emission.2/ Silicomanganese furnaces are subject to "slag boils," where slag rises up to cover the top surface of the charge, impeding mix delivery and uniform gas ascent.

Emissions from batch-operated furnaces are periodic. As a result of sudden addition of mix containing volatile constituents (coal volatiles, moisture, aluminum) to a hot furnace container, substantial violent gas eruptions can occur. This is best exemplified by the manganese ore-lime melt furnace where momentary gas flow following mix addition can be five times the average flow (as contrasted with variation of 20% or less in a well-running submerged-arc furnace). Temperature and dust loading peaks also correspond to the gas flow peak.

In contrast, chromium ore-lime melt furnaces, to which little or no gas releasing constituents are fed, are not subject to this violent behavior. In some circumstances, solids or molten material ejected from the furnace continue to burn in the air, giving rise to collection problems.

Some of the special alloys are also produced by aluminothermic reactions without the addition of electrical energy. These reactions, if unconfined, give rise to momentary peaks of gas flow.2/

Volatile materials in the furnace charge give rise to rough operation. Another significant contributor to rough operation is the presence of fines or dense material in the feed. These materials promote bridging and nonuniform descent of the charge, resulting in gas channeling and bypassing. Sudden collapse of a bridge then gives rise to a momentary gas burst. A porous charge will give good gas distributions and use of good quality scrap will also reduce emissions. On some products, economics dictate the use of raw materials with more fines, or with more volatile matter. Each of these has an adverse effect on the smooth operation of the furnace, and consequently pollution may increase.

Differences in operating techniques can have a significant effect on fume generation. The average rate of furnace gas production is roughly proportional to electrical input, so that a higher load on a given furnace generally results in at least a proportional increase in fume emission. In some circumstances, fume emission increases at a rate greater than the load increase, as a result of rougher operation and inadequate gas withdrawal capacity.

At a fixed load, even though the gas generation is almost constant, fume concentration and, hence, the weight per hour emitted can vary by a factor of 5 to 1. Operation with insufficient electrode submergence promotes increased fume emission. There is also some evidence that higher voltage operation, in addition to promoting a higher electrode position, alters the mode of energy release beneath the electrodes, increasing locally the energy supplied per unit volume, promoting higher local temperatures, and increasing the fume concentration.4/

On some operations, silicon metal production in particular, where stoking of the charge is necessary to break up crusts and partially agglomerated material and to cover up areas of blows, fume emission can be a function of how well and how often the furnace is stoked.

On other operations, where a mix seal and cover are used to allow collection of most or all of the furnace gas, direct venting and increased fume emission can occur if lack of mix prevents making a seal either because of poor mix placement or insufficient mix delivery. Direct venting can also take place during startup, shutdown, and "burndown" to remove undercover accumulations.2/

Loads on existing furnaces have been progressively increased as operating techniques improved and as more knowledge of transformer capacity became available. This tendency has taxed the furnace gas collection systems and, in the case of open furnaces, has certainly presented a more concentrated source of fume.2/

Maintenance practices significantly affect fume emission on covered furnaces, where accumulation of material under the cover and in gas offtakes and ducts reduces gas withdrawal capacity. Plugging of gas or water passages in cleaning apparatus results in reduced efficiency of gas cleaning.

Water leaks from electrode suspension equipment and other components above the furnace can result in some increase in gas flow (as steam or hydrogen).

17.3.1 Summary of Emission Rates

Table 17-1 presents a summary of emission rates from ferroalloy production. Particulate emissions currently total 160,300 tons/year. Electric-arc furnaces account for over 90% of this total (150,000 tons), and electric-arc furnaces producing ferrosilicon emit over 40% of the particulates (71,000 tons).

17.4 EFFLUENT CHARACTERISTICS

The chemical and physical properties of effluents from ferroalloy production processes are presented in Table 17-2. Properties of the emitted particulates depend upon the alloy being produced and furnace type. Particle size of the metallic fume emitted from the furnace ranges from 0.1-1.0 μ with a geometric mean of 0.3 μ. Grain loadings and flowrates are dependent upon furnace type. Open electric furnaces have high flowrates and moderate grain loadings while closed furnaces have moderate flowrates and generally high grain loadings.

With silicon alloys the fume produced is gray and contains a high percentage of SiO_2. Some tars and carbon are also present arising from the coal, coke, or wood chips used in the charge. Chromium furnaces produce a SiO_2 fume similar to a ferrosilicon operation with some additional chromium oxides. Manganese operations produce a brown fume. Analyses indicate the fume to be largely a mixture of SiO_2 and manganese oxides.

17.5 CONTROL PRACTICES

Limited sources of information have been found which describe control practices for ferroalloys. However, one very complete writeup by R. A. Person[1/] has been reviewed and excerpts used in the following description of control techniques and practices.

TABLE 17-1

PARTICULATE EMISSIONS PRODUCTION OF FERROALLOYS

Source	Quantity of Material	Emission Factor	Efficiency of Control C_c	Application of Control C_t	Net Control $C_c \cdot C_t$	Emissions (tons/yr)
I. Furnaces						
A. Blast Furnaces	591,000 tons, ferromanganese	410 lb/ton product*	0.99	1.0	0.99	1,200
B. Electric-Arc Furnaces	317,000 tons, ferromanganese	44 lb/ton	0.80	0.50	0.40	4,200
	285,000 tons, silicomanganese	195 lb/ton	0.80	0.50	0.40	16,500
	665,000 tons, ferrosilicon	357 lb/ton	0.80	0.50	0.40	71,200
	96,000 tons, silicon metal	583 lb/ton	0.80	0.50	0.40	16,800
	166,000 tons, silvery iron	120 lb/ton	0.80	0.50	0.40	6,000
	590,000 tons, ferrochrome, ferrophosphorus	200 lb/ton	0.80	0.50	0.40	35,400
II. Materials Handling	2,710,000 tons of metal produced	10 lb/ton of metal produced	0.90	0.35	0.32	9,000
		Total from Ferroalloys				160,300

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* All emission factors are "per ton of product."

TABLE 17-2

EFFLUENT CHARACTERISTICS - FERROALLOY MANUFACTURE*

A. Particulate

Source	Particle Size	Solids Loading	Chemical Composition	Particle Density	Electrical Resistivity	Moisture Content	Toxicity
I. Blast Furnace	(a) Dust (20% of emitted particulate) 100 > 20 (b) Fume (80% of emitted particulate) Range: 0.1-1 Avg. 0.3	4.5-17	Mn: 15-25 Fe: 0.3-0.5 $Na_2O + K_2O$: 8-15 SiO_2: 9-19 Al_2O_3: 3-11 CaO: 8-15 MgO: 4-6 S: 5-7 C: 1-2		See Table 17-3 for detailed data		Manganese compounds are poisonous
II. Electric Furnace							
(a) Ferrosilicon (50%) (open furnace)	Optical Count Range: 0.01-4 Geometric mean: 0.3 Standard deviation: 2-4	Range during cycle 0.2-2.7 Mean: 1.5	Hydrated silica: 92.8 X-Ray diffraction showed presence of: Si, Fe, Al, Ca, Mg, Mn, Cu and Ti		See Table 17-3 for detailed data		
(b) Miscellaneous alloys	See Table 17-4 for detailed data	0.4-30	See Table 17-4 for detailed data		See Table 17-3 for detailed data		

A. Particulates (Concluded)

Source	Solubility	Wettability	Hygroscopic Characteristics	Flammability or Explosive Limits	Handling Characteristics	Optical Properties	Odor
I. Blast Furnace				Fume is pyrophoric	Light, floury (fume component) ferromanganese fume forms a hard, cement-like deposit when wetted	Gray (ferromanganese)	
II. Electric Furnace							
(a) Ferrosilicon (50%)	1.5-4% in. H_2O						

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* See Coding Key, Table 5-1, Chapter 5, page 45, for units for individual effluent properties.

TABLE 17-2 (Concluded)

B. Carrier Gas

Source	Flowrate	Temperature	Moisture Content	Chemical Composition	Toxicity	Corrosivity	Odor	Flammability or Explosive Limits	Optical Properties
I. Blast Furnace	(a) 135 (one furnace) (b) 270* (one furnace)	350-750	Variable over cycle: 2-30	CO, CO_2, N_2 H_2, SO_2				Explosive because of CO content	
II. Electric Furnace									
(a) Ferrosilicon (50%, open furnace)		95-176							
(b) Ferromanganese (closed furnace)	(a) (b) 25.6-30.4	662		CO: 72 CO_2:11 H_2: 6 N_2: 10 CH_4: 1					
(c) FeCr Alloy (closed furnace)	(a) (b) 28.8-33.6	662		CO: 72 CO_2: 11 H_2: 6 N_2: 10 CH_4: 1					
(d) FeSi(75% Si, closed furnace)	(a) (b) 54.4-57.6	1832							
(e) Miscellaneous alloys									
(1) Open furnace	(a) 180-630* (b)	250-550							
(2) Semi-closed furnace	(a) 100* (b)	400-1200							
(3) Closed furnace	(a) 11-56								

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* Actual conditions.

TABLE 17-3

FERROALLOY FUME RESISTIVITY[1]

(ohm-cm, 200-300°F Temperature Range)

Product	Without Conditioning	With Conditioning of Gas to 20% Moisture
SMZ*	8.7×10^{13}	8.5×10^{11}
50% FeSi	1.2×10^{13}	9.3×10^{11}
FeMn	4.7×10^{11}	3.2×10^{8}
FeCr	9.4×10^{10}	2.1×10^{10}
SiMn	1.3×10^{10}	2.4×10^{8}

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* Si - 60-65%
Mn - 5-7%
Zr - 5-7%

TABLE 17-4

TYPICAL FERROALLOY FURNACE FUME CHARACTERIZATIONS

Furnace Product:	50% FeSi	SMZ*	SiMn**	SiMn**	FeMn	H.C.FeCr	Chrome Ore-Lime Melt	Mn Ore**-Lime Melt
Furnace Type	Open	Open	Covered	Covered	Open	Covered	Open	Open
Fume Shape	Spherical, sometimes in chains	Spherical, sometimes in chains	Spherical	Spherical	Spherical	Spherical	Spherical and irregular	Spherical and irregular
Fume Size Characteristics (μ)								
Maximum	0.75	0.8	0.75	0.75	0.75	1.0	0.50	2.0
Most Particles	0.05-0.3	0.05-0.3	0.2-0.4	0.2-0.4	0.05-0.4	0.1-0.4	0.05-0.2	0.2-0.5
X-Ray Diffraction	← All fumes were primarily amorphous →							
Primary Trace Constituents	FeSi $FeSi_2$	Fe_3O_4 Fe_2O_3 Quartz SiC	Mn_3O_4 MnO Quartz	Quartz SiMn Spinel	Mn_3O_4 MnO Quartz	Spinel Quartz	Spinel	CaO
Chemical Analysis - %								
SiO_2	63-88	61.12	15.68	24.60	25.48	20.96	10.86	3.28
FeO		14.08	6.75	4.60	5.96	10.92	7.48	1.22
MgO		1.08	1.12	3.78	1.03	15.41	7.43	0.96
CaO		1.01	--	1.58	2.24	--	15.06	34.24
MnO		6.12	31.35	31.92	33.60	2.84	--	12.34
Al_2O_3		2.10	5.55	4.48	8.38	7.12	4.88	1.36
LOI		--	23.25	12.04	--	--	13.86	11.92
TCr as Cr_2O_3		--	--	--	--	29.27	14.69	--
SiC		1.82	--	--	--	--	--	--
ZrO_2		1.26	--	--	--	--	--	--
PbO		--	0.47	--	--	--	--	0.98
Na_2O		--	--	2.12	--	--	1.70	2.05
BaO		--	--	--	--	--	--	1.13
K_2O		--	--	--	--	--	--	13.08

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* Si - 60-65%; Mn - 5-7%; Zr - 5-7%.

** Manganese fume analyses in particular are subject to wide variations, depending on the ores used.

The controls used are affected by the two types of electric furnaces. In the open furnace, all the CO produced burns with induced air at the top of the charge, resulting in a large volume of high temperature gas. In a closed furnace most or all of the CO is withdrawn from the furnace without combustion with air. When the furnace gas burns with air, as with an open furnace, a significant volume increase occurs. Depending on the amount of induced air, the volume to be treated for dust collection may increase by a factor of 50. Table 17-5 shows furnace gas generated without combustion while Table 17-6 gives a comparison of gas flows for open and closed furnaces.1/

Semicovered furnaces have also been used. The gas is usually cleaned in a multistage centrifugal fan with water spray nozzles. However, existing units are restricted to a capacity of about 2,000 acfm and are higher power and water consumers than a Venturi scrubber.

17.5.1 Control Equipment

17.5.1.1 Open Furnaces: Modern open furnaces require a hood to protect the superstructure and the electrode column components. A hood at least the diameter of the furnace shell, with the minimum opening between the hood and operating or charging floor, and an air inlet velocity of at least 3 ft/sec have been the criteria for recent installations. Sufficient hood depth must also be provided to assure that combustion is substantially complete within the hood.

Installed cost of fume collectors depends on the particular installation and the degree to which utility services are available. Estimated costs for units recently installed or planned on open furnaces, excluding furnace hood and interior ductwork and liquid waste disposal systems, are shown in Table 17-7.1/ These installed costs are 200-300% higher than would be estimated on the basis of general cost curves given in Appendix A.

17.5.1.1.1 Wet scrubbers: The only currently feasible type of wet collector for cleaning the large gas volumes from open furnaces is the Venturi type scrubber. With required pressure drops on the order of 60 in. w.g. the power consumption approaches 10% of the furnace rating (for a low hood design).1/ Most Venturi designs allow recirculation of scrubbing liquor so that water consumption is reduced to that evaporated into the gas plus that exiting with the concentrated solids stream. The Venturi has the advantage of being able to absorb gas temperature peaks by evaporating more water. For a ferrosilicon or ferrochrome-silicon operation substantially all of the sulfur in the reducing agent appears in the gas phase, and a corrosion problem occurs in any liquid recycle system unless neutralizing agents or special materials of construction are used.

TABLE 17-5

APPROXIMATE FURNACE GAS GENERATION1/

(Without Combustion)

Product	(SCFM/MW)
Silicon Metal	140-150
50% Ferrosilicon	130-140
Standard Ferromanganese	160-170
Silicomanganese	120-130
Ferrochrome-Silicon	110-120
H.C. Ferrochrome	80- 90
Calcium Carbide	70- 80

(Based on gas saturated at 100°F, scf at 30 in. Hg, 60°F)

TABLE 17-6

COMPARISON OF FURNACE GAS VOLUMES1/

	Closed Furnace	Open Furnace (Low Hood)
FeCrSi, 25 MW		
ACFM at Temp.	8700 at 1100°F	230,000 at 430°F
scfm	2900	135,000
50% FeSi, 50 MW		
ACFM at Temp.	20,000 at 1100°F	410,000 at 760°F
scfm	6,600	175,000

TABLE 17-7

ESTIMATED COST OF FURNACE CONTROLS1/

	Estimated Installed Cost (1969) $/ACFM at Furnace Hood
Venturi Scrubber	2.40 - 3.60
Bag Filter	2.90 - 3.60
Electrostatic Precipitator (with conditioning)	3.80 - 4.20

Recent wet scrubber installations are summarized in Table 17.8.[1]

17.5.1.1.2 Baghouses: Cloth-type filters do an effective job of cleaning the combustion gases from open furnaces so long as the filter media remain intact. Baghouse installations often utilize the pressure-type baghouse, with the fan on the dirty-gas side, to simplify the collector housing construction and to allow access into the collector during operation. To prevent carryover of burning mix particles, a mechanical collector ahead of the baghouse is desirable.[1]

Because of temperature limitations on the cloth (500°F for treated fiberglass), the gas must often be cooled by passing through heat transfer surfaces or by dilution. Cooling by water spray injection is possible, but can lead to control complications and possible blinding of the bags.

The amount of gas a cloth filter can handle when operating on silica fume without bag blinding is a maximum of about 2 acfm/sq ft of filter area. This limit results in a large number of bags, up into the thousands, in order to treat the combustion gas from an open furnace.

A significant problem associated with the use of fiberglass bags on silica fume collection is the buildup of electrostatic charge, which in turn leads to a high residual pressure drop across the bags.

17.5.1.1.3 Electrostatic precipitators: Electrostatic precipitators have been installed on open furnaces producing silicon, ferrosilicon, ferrochrome-silicon, and silicomanganese.

Unfortunately, most ferroalloy fumes at temperatures below 500°F have too high an electrical resistivity, i.e., greater than 1×10^{10} ohm-cm. The resistivity is in an acceptable range only if the gas temperature is maintained above 500-600°F. Water conditioning would lower the resistivity, but a large spray tower is required for proper humidification. Stainless steel construction would be a necessity for ferrosilicon or ferrochrome-silicon operations. The alternate use of steam is feasible only if low-cost steam is available.

The resistivity problem could be overcome by using a wet precipitator, but water usage appears to be greater than that for a wet scrubber without recycle.[1] Wet electrostatic precipitators have been used at one installation in Europe. However, all parts of the precipitators exposed to the dirty water and to the wet gas were reconstructed of stainless steel.[6] An electrostatic precipitator is being installed on a ferroalloy furnace by AIRCO at Charleston, South Carolina.

TABLE 17-8

EXAMPLES OF FURNACE WET SCRUBBERS1/

Collector	Open Furnace - Low Hood			Semi-Closed Furnace
	I	II	III	IV
Original Completion Date	1967	1968	1968	1965
Furnace Rating for Collector Design	25 MW	30 MW	30 MW	45 MW
Furnace Product	FeCrSi	SiMn	H.C. FeCr	50% FeSi
Measured Collection Efficiency, Avg.	92.6%	98.6%	98.2%	98.4% (particulates) 79% (organics)
Inlet Loading, grains/scf	1.43	1.31	1.07	4.93
Outlet Loading, grains/scf	0.106	0.017	0.019	0.08
Design Volume at Furnace Hood	230,000 ACFM	255,000 ACFM	210,000 ACFM	--
Design Temperature	430°F	620°F	590°F	--
Actual Duct or Offtake Temperature	500 to 570°F	490 to 550°F	480°F	1100 to 1200°F
Design Volume Handled by Fans or Blowers	194,000 ACFM	196,000 ACFM	196,000 ACFM	6,500 scfm
Operating Pressure Drop across Collector, inches water	55	57	57	72 to 80
Installed H.P. - Fans	2,600	2,800	2,800	600
- Auxiliaries	50	50	50	--
Tons/Day Collected Dust	11 to 13	14 to 17	11 to 17	5 to 8
Tons/Day Uncollected Emission	0.75 to 1	0.20	0.26	None
Water Circulation	1,800 gpm	1,800 gpm	1,800 gpm	75-100 gpm
Water Usage	310 gpm	350 gpm	350 gpm	75-100 gpm
Problems:	(1) System falls 25% short of design flow. (2) High fan outage. (3) Necessity to add lime to neutralize scrubbing liquid.	(1) High fan outage.	(1) High fan outage.	(1) Continuous kerosene injection necessary for blowers.

17.5.1.2 Covered Furnaces: Semicovered furnaces, while collecting a majority of the fume, may not in many cases be satisfactory for current or pending regulation.

The sealed furnace, which has a cover including sliding seals around the electrodes and mix spouts, is primarily a European development. It has thus far been applied only to calcium carbide, pig iron, standard ferromanganese and silicomanganese. Sealed covers are difficult to adapt to an existing furnace because of the extensive revisions that are usually required.

A modified cover, incorporating electrode seals, but covering only the "reaction zones" around the electrodes and leaving the outer rim of the furnace open, has been developed. This approach, called gas collection sleeves or smoke rings, has the advantages of collecting the gas in the observed region of maximum generation, of allowing partial stoking of the mix, and of being cheaper than a complete cover. Initial installations were made on ferromanganese furnaces and subsequently on calcium carbide and silicomanganese furnaces.1/

17.5.1.2.1 Wet scrubbers: The disintegrator type of scrubber does a good cleaning job when properly maintained and has the additional advantage of producing a slight pressure head (about 2 in. w.g.). However, the capacity limitation and high water and power consumption make it uneconomical for most new furnace installations.

The Venturi type scrubber has been installed on CO gas cleaning installations but the required pressure drops are high. The characteristics of a typical installation are included in Table 17-8.1/

17.5.1.2.2 Electrostatic precipitator: The electrostatic precipitator is a possible CO gas cleaning device, but has found limited ferroalloy application.

17.5.1.2.3 Baghouses: It would be possible to use a bag collector to clean CO gas, but no applications on ferroalloy furnaces are known.

17.5.1.3 Blast Furnaces: Blast furnaces are also used for ferroalloy production including ferromanganese. Wet scrubbers are used in cleaning the emitted gases. High maintenance costs may attend such an operation because of the cementing properties of the fume. It also requires a large-scale water-treating plant to avoid stream pollution.

For these reasons, one producer conducted pilot testing of an electrostatic precipitator preceded by a spray cooler. The collected dust from the precipitator, being pyrophoric, was burned in a rotary kiln and the product was then briquetted.[3,7,8]

One Venturi scrubber installation in England reportedly cleaned the gases from a ferromanganese blast furnace to less than 0.02 grain/cf. This unit required a pressure drop of 24 in. w.g. and a water flow of 5 gal/1,000 cf of gas.[10]

Sonic agglomeration of fume from a ferromanganese blast furnace was investigated in 1950 but was not economically attractive.[9]

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CHAPTER 18

IRON FOUNDRIES

18.1 INTRODUCTION

Gray iron foundries range from primitive, unmechanized hand operations to highly mechanized plants in which operators are assisted by electrical, mechanical, and hydraulic equipment. Cupola, electric-arc, electric-induction, and reverberatory air furnaces are used to obtain molten metal for production of castings.

The iron melting process in foundries is the principal source of emissions. Secondary sources include materials handling, casting shakeout systems, buffing and grinding operations, and core ovens. The production process, particulate emission sources, particulate emission rates, effluent characteristics, and control practices and equipment are discussed in the following sections.

18.2 FOUNDRY PROCESSES

The gray iron cupola in its simplest form is a vertical, hollow shaft having a steel shell either lined with refractory or backed by a water curtain for temperature control. A charging door located above the bottom of the cupola admits the charge which consists of alternate layers of coke, iron materials, and flux. Tuyeres, located near the bottom of the cupola, admit air for combustion. Provision is made for removing slag and molten iron from openings below the tuyeres, the iron being tapped from the bottom level and slag tapped or skimmed from above the iron.

Electric-arc and induction furnaces are mostly used to produce specially alloyed irons. Fuels are not used in the heating process in these furnaces.

18.3 EMISSION RATES FROM IRON FOUNDRIES

Physical processes, chemical reactions, and the quality of scrap affect the emissions of dust and fumes from cupolas. Physical processes include entrainment of coke, lime and oil or grease particles. Non-uniform combustion results in variations in emissions. An oily charge can evolve huge volumes of black smoke and fine chips can significantly increase metal fuming rates. Because of the wide divergence of ratios of charge materials utilized, and the varying quality of the scrap, no simple accurate estimate can be made of the nature and quantity of pollutants emitted from foundry cupolas.

Quality and composition of emissions vary between cupolas and even at intervals in the same cupola. This variation is caused by changes in iron-to-coke ratios, air volume/ton melted, and quality of scrap. A charge containing limestone with a low degree of hardness and a large portion of fines will produce a relatively high dust content in the waste gases. The abrasion resistance and ash content of the coke also has an effect on the dust emission level. Emissions from hot-blast cupolas are generally higher than from cold-blast cupolas. This is probably due to larger quantities of small steel scrap being charged into the hot-blast cupolas, and is not a direct function of the combustion air temperature, blast volume, or other operating parameters.

Emissions of sulfur compounds are usually low because sulfur content of coke is generally 0.6% or less. SO_2 concentrations have been observed to vary between 25 and 250 ppm.9/ These concentrations, when combined with moisture, can form enough sulfuric acid to corrode surrounding equipment. Fluorine and/or HF from fluorspar may be emitted, probably in small quantitites.1/

Electric-arc furnace emissions are less of a problem than cupola emissions. Since these furnaces are mostly used to produce special alloy irons, the quality of material charged is better and freer from dirt and oils. Emissions are primarily metallic fumes; the quantity emitted varies from 5 to 10 lb/ton of metal charged.2/

Emissions from electric-induction furnaces are even less of a problem than those from the electric-arc furnaces. Use of clean scrap, minimum exposure of the metal to air while in the furnace, and uniform operation of the furnace usually result in negligible quantities of emissions. The quantity of emissions, primarily metal oxides, is about 2 lb/ton of metal charged.2/

Apart from the cupola, other sources of iron foundry emissions are casting shakeout systems, buffing and grinding, and core ovens. The magnitude of these emissions is low compared to cupolas.

Table 18-1 summarizes emissions from operations associated with gray iron foundries. Cupola emissions are dominant, and currently total about 105,000 tons/yr. No estimate of emissions from casting shakeout systems, buffing and grinding operations, and core ovens was made due to lack of emission data from these secondary sources.

TABLE 18-1

PARTICULATE EMISSIONS

IRON FOUNDRIES

Source	Quantity of Material	Emission Factor	Efficiency of Control C_c	Application of Control C_t	Net Control $C_c \cdot C_t$	Emissions tons/yr
I. Furnaces	18,000,000 tons of hot metal	16 lb/ton of hot metal	0.80	0.33	0.27	105,000
A. Cupola						
1. Hot blast		15 lb/ton of hot metal				
a. externally fired		--	--	--	--	
b. recuperative		--	--	--	--	
2. Cold blast		23 lb/ton of hot metal				
B. Electric						
1. Arc		5-10 lb/ton	--	--	--	
2. Induction		--	--	--	--	
C. Reverberatory		--	--	--	--	
II. Materials Handling		*5 lb/ton of hot metal	*0.80	*0.25	*0.20	37,000
A. Freight Unloading--Coke and Limestone		--	--	--	--	--
B. Conveyors						
1. Transfer points		--	--	--	--	--
2. Discharge to storage		--	--	--	--	--
a. bins, silos						
b. stockpiles						
C. Elevators		--	--	--	--	--
1. Boots		--	--	--	--	--
2. Heads		--	--	--	--	--
D. Sand Handling	10,500,000 tons of sand	0.3 lb/ton of sand	--	--	--	1,000
III. Core Ovens		0.3 lb/gal of core oil	--	--	--	--
IV. Shell Core Machines		0.35 lb/ton of cores	--	--	--	--
V. Casting Shake-out System		--	--	--	--	--
VI. Grinding and Buffing		--	--	--	--	--
						143,000

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* Assumed.

18.4 CHARACTERISTICS OF EFFLUENTS FROM IRON FOUNDRIES

The chemical and physical properties of effluents from iron foundries are summarized in Table 18-2. Cupola dust is a very heterogeneous mixture. Particulates contain coke and flux particles, various metals, their oxides, and some sulfates. Silica content is high, particularly in the 0-10 μ fraction. Of the metals portion, 60% are oxides of Si and Fe. Significant zinc and lead oxides are also found. Other elements found in the particulates include manganese, chromium, tin, titanium, molybdenum, zirconium, nickel, copper, cobalt, and silver.[3,4] About 25-30 wt. % of the particulates are less than 10 μ. The particle size distribution ranges between wide limits, depending on melt rate, coke usage, scrap formulation, and furnace operating variables. Under some conditions, over 50% of the dust may be less than 1 μ in diameter, whereas in other cases less than 5% by weight of the total particulate may be under 2 μ in diameter. Older data indicate no more than 10% of the particles by weight are in the size range below 10 μ. However, later studies indicate that particle sizes under 1 μ may constitute 40% and more of the total weight. Some of the scatter between the various investigations may be a result of differences in sampling equipment and techniques and of sampling at different locations in the ductwork.

18.5 CONTROL PRACTICES AND EQUIPMENT FOR IRON FOUNDRIES

18.5.1 Electric Melting Furnaces

The extremely fine particle size and large surface area of electric-furnace fume result in discharge to the atmosphere of a plume that may not meet the visibility restrictions in some air pollution codes, even when weight requirements are met. The concentration of particulate in the effluent air from an electric-furnace fume control system may have to be less than 0.05 grain/cu ft of air if an emission is to satisfy an equivalent opacity restriction.[5]

There have been several electrostatic precipitator installations to control particulates from larger furnaces and there are about 50 installations imploying fabric filter collectors. Fabric filter collectors generally result in an effluent nearly free from visible particulates.[5]

The collection of fumes from the electric furnace has been done by using canopy hoods to gather the expanding, rising gas column, by local exhaust around electrodes and charging doors, and by direct evacuation of the furnace itself.[4]

TABLE 18-2

EFFLUENT CHARACTERISTICS - IRON FOUNDRIES+

Particulate							
Source	Particle Size	Solids Loading	Chemical Composition	Particle Density	Electrical Resistivity	Moisture Content	Toxicity
Iron Foundry							
Gray Iron Cupola:							
1. Light-off period		0.001-0.36					
2. Melting period		0.8-1.6					
3. Complete heat	$2\text{-}30 < 5$, $2\text{-}35 < 10$, $10\text{-}40 < 20$, $20\text{-}60 < 50$ Average distribution: $10 < 5$, $22 < 10$, $25 < 20$, $35 < 50$ Bahco analysis: (two tests) $20\text{-}54 < 5$, $37\text{-}63 < 10$, $52\text{-}72 < 20$, $66\text{-}77 < 40$ Also see Figure 18-1	Extreme range: 0.3-15 Usual range: 1-3 Average: 1.2	Mean range: SiO_2: 20-40 CaO: 3-6 Al_2O_3: 2-4 MgO: 1-3 FeO(Fe_2O_3,Fe): 12-16 MnO: 1-2 Ignition loss (C,S): 20-50 Other components may be present depending on charge composition	Mean value: 2.5-3.1	See Figures 18-2 and 18-3 for detailed data		

Source	Solubility	Wettability	Hygroscopic Characteristics	Flammability or Explosive Limits	Handling Characteristics	Optical Properties	Odor
Foundry							
Gray Iron Cupola	CaO- s. H_2O CaO, SiO_2, Al_2O_3 - s. 10% HCl	Difficult to wet			Abrasive, cohesive, corrosive	Variable, dependent on charge composition	

+ See Coding Key, Table 5-1, Chapter 5, page 45, for units for individual effluent properties.

TABLE 18-2 (Concluded)

Carrier Gas

Source	Flow Rate	Temperature	Moisture Content	Chemical Composition	Toxicity	Corrosivity	Odor	Flammability or Explosive Limits	Optical Properties
Iron Foundry									
Gray Iron Cupola									
1. Light-off period	(a) 3-16			CO_2: 0.3-10.3 O_2: 10.1-20.5 N_2: balance					
2. Melting point	(a) 5-20.5			CO_2: 2-13.4 O_2: 6.5-19.2 SO_2: 0.002-0.013					
3. Complete heat	(a) 3-30.5 Avg. 10.8 (b) 60-135 Avg. 92	210-1410	Top gas dew point, 60	CO_2: 2.8-12.3 O_2: 11.8-12.7 CO: 0-0.1 SO_2: 0.002-0.013 Fluorides may also be emitted depending on flux material	SO_2 - 5, irritant CO-100	Potentially corrosive due to SO_2			

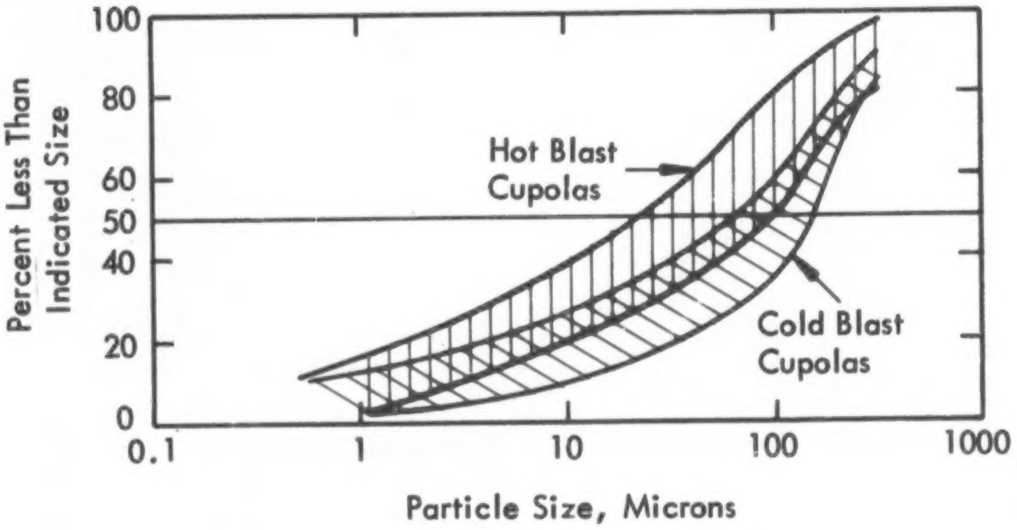
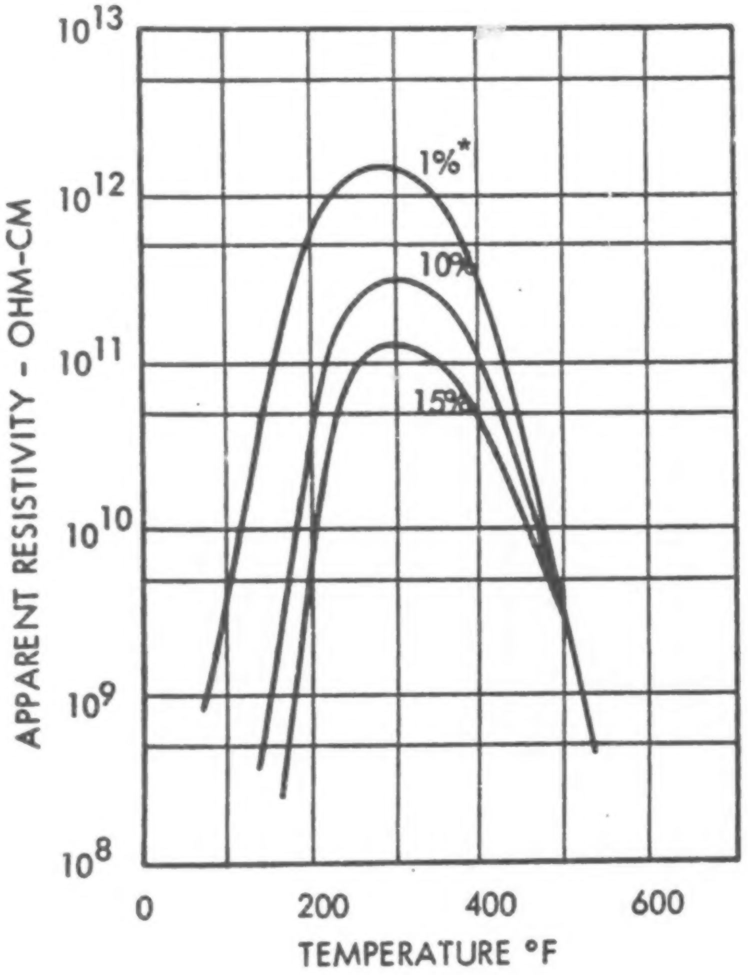


Figure 18-1. Particle Size Ranges for Dusts from Cold- and Hot-Blast Cupolas.[3]



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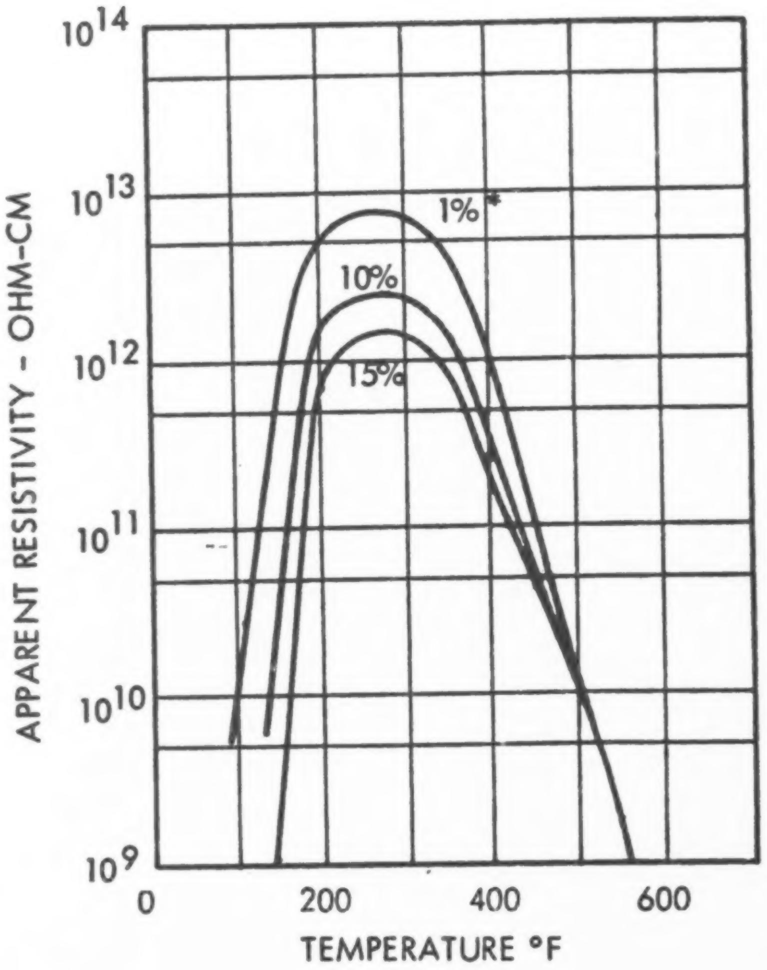
* Figure shows percent water vapor by volume.

Figure 18-2 - Apparent Resistivity of Dust and Fume in Plant A.



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* Figure shows percent water vapor by volume.

Figure 18-3 - Apparent Resistivity of Dust and Fume in Plant B.

18.5.2 Cupola Furnace

Only electrostatic precipitators, high-energy scrubbers, and fabric filters are capable of removing the fine particles from cupola gases. Regardless of whether electrostatic precipitators or baghouses are used as the means of gas cleaning, it is necessary to maintain efficient secondary combustion in the cupola stacks (recuperative preheater). Otherwise, the operation of the gas-cleaning equipment is adversely affected. Maintaining a reducing atmosphere in the cupola stack will allow unburned oil vapor and tarry matter, as well as coke fines and other combustibles, to be carried over into the gas-cleaning equipment. The secondary combustion process does, however, cause an increase in the volume of the gases to be treated.5/

General collector selections and efficiency for the various foundry operations are shown in Tables 18-3, -4, and -5 taken from "Foundry Pollution Control Manual."1/

Relative cost comparisons of the various types of dust collectors applied to hot-blast cupola waste gases are presented in Table 18-6. This table gives costs with respect to a Venturi type collector which has been assigned an index value of 1.00 and does not show absolute dollar costs.3/ Another cost comparison for different types of collectors for a 12 ton/hr cupola is given in Table 18-7.4/ Collector characteristics for a 15 ton/hr cold-blast cupola are shown in Table 18-8.5/ The approximate cost of cupola collector systems is shown in Table 18-9.6/

TABLE 18-3

IRON FOUNDRY DUST COLLECTOR EFFICIENCY[1/]

			Typical Outlet Loading (gr/scf)					
Application	Particle Size	Typical Inlet Loading (gr/scf)	Wet Cap	6 in. ΔP Scrubbers	30-70 in. ΔP* Scrubbers	Low Eff. Cyclone	Fabric Arrester	Comments
Shakeout	Fine to medium	1/2-1	X	0.01	X	X	X	Wet scrubbers are used because of moisture.
Sand cooler	Medium	1-20		0.01-0.05	X	X	X	Wet scrubbers are used because of moisture.
Airless abrasive cleaning	Fine to coarse	1/2-5	X	0.01-0.05	X	X	0.01	Fabric filters and wet scrubbers most common.
Grinders	Coarse to medium	1/2-2	X	0.01	X	0.1	0.01	Cyclones used when fines are not present.
Dry sand reclaimer	Coarse to fine	10-40	X	0.1	0.02-0.05	X	0.01	Disposal problems generally influence choice of equipment.
Screens and transfer points	Medium	1/2-3	X	0.005-0.01	X	X	0.01	
Electric-arc furnace	Fine	1/2-2	X	0.2	0.02	X	0.01	Fabric filters more frequently used than others.
Gray Iron Cupola	Coarse to fine	1/2-10	0.4	0.3	0.05	0.4	0.01	All types in use.

Notes: Coarse +20 µ; Medium 2.20 µ; Fine 2 µ.
* Or equivalent energy input.
X Not applicable or rarely used on this application.

TABLE 18-4

USUAL COLLECTOR SELECTIONS FOR FOUNDRY OPERATIONS[1/]

Operation	Dust Emission		Collector Types Used in Foundry Industry						Remarks
	Concentration*	Particle Size**	Common Cyclone	High Eff. Cyclone	Wet	Fabric	Electrostatic	Catalytic Combus.	
Shakeout (Mechanical)									
Enc. Hood	Moderate	Fine to medium	Rare	Occasional	Usual	Occasional	No	No	1
Side Hood	Light	Fine	No	Rare	Usual	Occasional	No	No	1
Sand Handling									
Molding sand from Shakeout	Moderate	Fine to medium	Rare	Occasional	Usual	Rare	No	No	2
New sand	Moderate	Fine to medium	Rare	Occasional	Usual	Occasional	No	No	3
Core sand	Light	Medium	Rare	Occasional	Usual	Occasional	No	No	4
Casting Cleaning									
Airless abrasive	Heavy	Fine to coarse	No	Rare	Occasional	Usual	Rare	No	5
Blast Rooms	Moderate	Fine to medium	No	Rare	Usual	Usual	No	No	5
Tumbling mills	Heavy	Fine to coarse	No	Rare	Usual	Usual	No	No	6
Sprue mills	Moderate	Fine to coarse	No	Occasional	Usual	Usual	No	No	6
Grinding									
Snagging	Moderate	Medium to coarse	Frequent	Frequent	Frequent	Frequent	No	No	
Swing frame	Light	Fine	Rare	Frequent	Frequent	Frequent	No	No	
Portable	Light	Fine to medium	Rare	Frequent	Usual	Usual	No	No	
Core	Heavy	Medium to coarse	Rare	Occasional	Usual	Usual	No	No	7
Melting									
Cupola (ferrous)	Moderate	Fine to coarse	Rare	Occasional	Frequent	Occasional	Occasional	No	8
Electric (ferrous)	Light	Fine	No	No	Occasional	Frequent	Rare	No	9
Brass melting	Light	Fine	No	No	Occasional	Frequent	Rare	No	10
Pattern Shop									
Woodworking	Moderate	Medium to coarse	Usual	Rare	Rare	Occasional	No	No	11
Boiler Fly Ash									
Chain grate	Light	Medium	No	Occasional	No	No	No	No	12
Spreader stoker	Medium	Medium to coarse	No	Usual	No	No	No	No	12
Pulverizer	Heavy	Medium	No	Usual	No	No	Frequent	No	12
Core ovens	Comb. fumes	Comb. fumes	No	No	Rare	No	No	Frequent	
Paint ovens	Comb. fumes	Comb. fumes	No	No		No	No	Frequent	
Oil burn-off Furnaces	Comb. fumes	Comb. fumes	No	No	Rare	No	No	Frequent	

---

* Concentration: Light - up to 1 gr/cu ft; Moderate - 1 to 3 gr/cu ft; Heavy - over 3 gr/cu ft

** Particle Size: Fine - under 2 μ; Medium - 2 to 20 μ; Coarse - over 20 μ.

Notes:

(1) Loadings increase with metal to sand ratio and with lower moisture content of sand at time of shakeout. Smoke from burning seacoal and core binders often involved as well as steam.

(2) Concentration of dust is a function of moisture remaining in sand following the shakeout operation. Traps or dry centrifugal collectors sometimes used to return coarser particles to sand system. Water from wet collectors sometimes used at mixer to permit salvage of seacoal and bond as well as retard slurry formations in recirculated water.

(3) Collection equipment for molding sand handling system can often be used for dust collection during the shorter period of new sand handling.

(4) Dust problems very similar to those for molding sand system.

(5) Dust problem from abrasive cleaning operations was one of the earliest in the foundry industry for which high efficiency collectors were universally applied. Airless blasting produces heaviest loads due to abrading speed. Blast rooms where shot or grit is employed exhaust much larger air volumes for the dust released.

(6) The tumbling action employed has tendency to grind or pulverize sand and scale particles, producing a substantial fraction of dust loading in low micron sizes.

(7) Collectors are indicated wherever production core grinders are used.

(8) Wet primary collectors on top of cupola stack used where damage to roof or excessive cost of removal of cinder accumulation is main consideration. Fabric arresters or electrostatic precipitators selected in most critical air pollution areas where visible effluent must be minimized.

(9) While wet collectors have been usual selection in past, the fabric arrester appears the more usual selection for future installations due to its ability to provide a clear discharge. Relatively low temperatures make cost of such installations reasonable.

(10) Collection of zinc oxide is receiving increasing attention where high zinc brass alloys are melted. Fabric arresters provide high efficiency at reasonable cost where gas temperatures are moderate as from crucible, electric, and induction melting furnaces. High stack temperatures of reverberatory furnaces make problem more complex and collection equipment expensive.

(11) Cyclone or dry centrifugal usual selection. Can be followed by fabric collectors where recirculation of cleaned air is indicated.

(12) Fly ash from boiler stacks is often overlooked by the foundry industry but can be source of nuisance attributed to other stack discharges. High efficiency dry centrifugals provide degree of collection generally acceptable by present-day standards. High temperature and corrosive gases make better collection very expensive.

TABLE 18-5[1]

EFFICIENCY TESTS OF DRY MULTIPLE CYCLONES FOR FIVE DIFFERENT INSTALLATIONS

Melting Rate (ton/hr)	Dust Loading Collector Inlet (lb/1,000 lb)*	Dust Loading Collector Outlet (lb/1,000 lb)*	Overall Efficiency (%)
14.4	1.053	0.335	69
21.6	1.324	0.515	61
15.5	1.040	0.300	71
22.5	0.855	0.288	66
14.7	1.061	0.262	75

---

* Pounds of particulate matter per 1,000 lb. of flue gas.

TABLE 18-6[3]

COST COMPARISON FOR VARIOUS DUST COLLECTORS FOR CLEANING WASTE GASES OF A HOT-BLAST CUPOLA

(Index value 1 for Venturi tube dust separation)
Waste gas quantity to be cleaned: 7,350 scfm Depreciation: 20% per annum

Plant	Venturi Tube Dust Collector	Wet Dust Collector, Simple Design	Dry Electro-Precipitator		Wet Electro-precipitator	Fabric Dust Collector	
			Offer 1	Offer 2		Offer 1	Offer 2
Guaranteed clean dust content: lb/hr	7.70	7.70	3.85	5.70	3.85	5.28	3.30
gr/scf	0.122	0.122	0.061	0.09	0.061	0.084	0.052
Initial investment costs (index value)	1.00*	1.04*	3.24	1.68	1.59*	1.45	2.36
Depreciation and interest (index value)	1.00*	1.04*	3.24	1.68	1.59*	1.45	2.36
Power consumption (index value)	1.00	0.62	0.23	0.36	0.24	0.65	0.43
Maintenance, servicing, water consumption, neutralization (index value)	1.00	1.06	0.62	0.536	0.83	0.55	0.54
Costs per operation hour (index value)	1.00*	0.88*	1.67	1.01	0.96*	1.14	1.50

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* Without facilities for water supply and settling tank.
Table does not include erection costs.

TABLE 18-7[4]

APPROXIMATE COST OF CONTROL EQUIPMENT
(12 ton/hr cupola)

Weather Cap	$ 30,000
Dry Centrifugal	60,000
Medium Pressure Wet	90,000
High-Temperature Fabric	150,000
High-Energy Wet	170,000

TABLE 18-8[5]

COLLECTOR CHARACTERISTICS FOR 15 TONS/HR COLD-BLAST CUPOLA OPERATED ON ALTERNATE DAYS

Assume Blast Volume = 8,000 cfm at 70°F
Charging Door 40 sq. ft. at 300 fpm = 12,000 cfm at 70°F
Total Gas Volume = 20,000 cfm at 70°F
= 62,500 cfm at 1,200°F

Assume Emissions 15 = hr. ton melt
Consisting of Cinders 8 = hr. ton melt
Dust 4 = hr. ton melt
Fumes 3 = hr. ton melt

Collector Type	Discharge Gas Temperature (°F)	H_2O Vapor at Exit Temp. Added for Cooling (cfm)	Total Vol. at Exit Temp.	Lower Effective Collection Range (μ)	Collector Pressure Drop W.G. (in.)	Probable H.P. Note 1 Exit Temp.	Probable H.P. Note 1 70	Water Required (gpm)	Probable Emission Note 2 (grains/scf)	Probable Emission Grains/cfm at 500	Approx. Instal. Cost on Existing Cupolas
Wet cap	400-700	9,850	47,850 cfm at 550°F	44	0.25	--	--	200	0.45	0.25	$ 35,000
Low pressure drop centrifugal with cooling tower	350-500	10,200	43,600 cfm at 425°F	30	1.5	24	40	34.3	0.36	0.20	50,000
With heat exchanger	600-700	None	41,800 cfm at 650°F	30	1.5	34	71	0	0.45	0.25	150,000
High eff. dry centrifugal	350-500	10,200	43,600 cfm at 425°F	7	3.0	34.3	57	34.3	0.27	0.15	55,000
Wet collectors	125-190	9,750	33,750 cfm at 175°F	1	5.0	52.5	63	48-100	0.11	0.062	75,000
Electric precipitator	250-300	10,200	38,000 cfm at 275°F	0.1	0.5	18	25	41.2	0.039	0.021	100,000
Fabric arresters Synthetic fabric	250-275	9,600	36,800 cfm at 260°F	0.1	4.0	42.5	57.5	41.8	0.0096	0.0053	75,000
Glass fabric	400-500	10,200	44,200 cfm at 450°F	0.1	4.0	40.5	69.5	33.2	0.0206	0.0114	75,000

Note 1: Horsepower calculations assume pressure loss through ducts and cooling tower of 2 in. added to stated collector loss except for wet cap (5 in. with heat exchanger).

Note 2: Lower than the usual boiler stack acceptable emission regulations of 0.257 grain/cu ft at 500°F (0.465 grain/scf).

TABLE 18-9

COMPARISON OF CUPOLA DUST CONTROL SYSTEMS[6]

(Two No. 8 Cupolas--7,800 cfm blast air alternate usage--1 grain/scf dust load)

Equipment	Initial Cost Installed In \$1,000's[a]	M & O Cost/Year In \$1,000's[b]	Outlet Emission, Grain/scf[c]	Connected Horsepower[d]
Wet cap	50	3	0.5	20
Multitube cyclone	150	10	0.3	100
6 in. ΔP scrubber	150	10	0.2	100
70 in. ΔP scrubber	225	25	0.05	325
Fabric filter	250	Wide variations	< 0.02	100

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a/ With water clarification system and ductwork, electrical, etc.

b/ Maintenance and operating cost per year, including power costs for 16 hr/day operation, but not depreciation.

c/ Outlet emission also dependent on particle size distribution, which in turn is dependent on scrap quality, etc.

d/ Connected horsepower, including pump for wet units.

18.5.3 Electrostatic Precipitators

Electrostatic precipitators have failed to attain consistently high collection efficiencies due to wide variation of gas stream conditions. To satisfactorily apply electrostatic precipitation to foundry-cupola-fume collection, it is essential to determine the temperature at which the peak resistivity of the fume occurs, and to design the gas conditioning system to provide a gas temperature well away from that at which the resistivity reaches its maximum. Electrostatic precipitators have been employed in Europe to a greater degree for cupola operations and utilize both wet and dry electrode cleaning techniques. Data on some of these units are given in Table 18-10.[3/]

18.5.4 Fabric Filters

There are several installations employing completely automatic, tubular dust collectors using synthetic filter bags in conjunction with cooling of the hot gases prior to filtration. The primary difficulty in their use arises from poor control of inlet gas temperature. When it is too high, the bags burn out; when it is too low, the fabric blinds from condensation of water vapor.[5/] The fabric collector temperature is generally limited to the capability of the fabric media and, at present, glass is operable up to 550°F.

Fabric filters are being used increasingly for cleaning cupola gases whenever high collection efficiencies are desired. Operating characteristics for three installations are given in Table 18-11.[3/]

The temperature of the gas stream from the top of a cupola may be as high as 2200°F. Therefore, the gases must be cooled, prior to entering the baghouse. Cooling can be effected by evaporative water or other means of heat exchange or by dilution with ambient air.

It should be remembered that if fluorspar is used as a fluxing agent in the cupola, this can be damaging to glass-fiber bags.

General cost data for fabric filters given in Appendix A indicate that an installed cost of \$3.50/acfm would apply to a unit handling about 10,000 acfm. This decreases to less than \$2.00/acfm for 50,000 - 100,000 acfm.[7/]

Installed cost of baghouses ranges from \$0.93 to \$3.50/acfm. Installation expense ranges from 12-43% of the FOB price with the average being 25%. Annual operating and maintenance expense ranges from 5-16% of the installed cost with an average of 11.6%.[1/]

TABLE 18-10

CUPOLA PLANTS WITH ELECTRO-PRECIPITATORS[3/]
(European Installations)

No.	Furnace Type	Melting Rate (T/hr)	Filter Type	Type of Gas	Gas Temperature			Clean Gas Volume scfm Dry	Dust Content		Collection Efficiency (%)	Dust Emission in the Atmosphere (Lb/Hr)	Pressure Loss of the Unit (In. W.G.)	Water Requirement (Circulation and Make-Up Water) (gpm)
					Before Cooler (°F)	Before Filter (°F)	After Filter (°F)		Raw Gas Grain/scf Dry	Clean Gas Grain/scf Dry				
1	Hot Blast	13.2	Dry	Top	--	Up to 750	App. 570	6,500	7-9.2	0.05-0.07	98.5-99.7	3.26	1	--
2	Hot Blast	16.5	Dry	Top	930-1,110	570	*	6,800	Up to 4.3	0.065	98.5	3.79	*	--
3	Hot Blast	6.6	Dry	Waste	*	149	*	8,200	*	*	97.6	*	*	--
4	Hot Blast	6.6	Wet	Top Plus Waste	*	140	*	4,800	1.22	0.021	98.3	0.845	*	*
5	Hot Blast	8.8	Wet	Waste	390	*	104	19,000	0.70	0.033	95.0	5.30	6.3**	264
6	2 Hot Blast Units	20.0	Wet	Waste	750-840	*	*	29,000	2.2	0.043	98.0	11.00	*	*
7	Hot Blast Externally heated	19.0	Wet	Top	680	*	122	7,200	3.09	0.037	98.85	2.26	6.5	200
8	Hot Blast	13.4	Wet	Top Plus Waste	500	*	131	9,200	4.65	0.062	97.0	6.17	3.5	138

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* No data available.

** Pressure loss inclusive connecting pipelines.

TABLE 18-11

CUPOLA DUST REMOVAL INSTALLATIONS WITH FABRIC FILTER[3]

No.	Furnace Type	Melting Rate (T/hr)	Dust Removal Plant	Pressure Drop In. W.G.	Gas Temperature			Gas Quantity Before Filter		Dust Content			Collection Efficiency (%)	Dust Discharge in Atmosphere (lb/hr)
					Cupola Exit (°F)	Filter Inlet (°F)	Filter Exit (°F)	scfm	scfm Dry	After Cupola Grain/scf Dry	Before Fabric Filter Grain/scf Dry	After Fabric Filter Grain/scf Dry		
1	Cold Blast	5.0	Waste gas cleaning closed glass fabric filter	4	1,380	446	230**	8,400	4,500	*	1.19	0.0015	99.83	0.073**
2	Hot Blast	33.0	Top gas cleaning (part of gas quantity) closed glass fabric filter	About 14 in. W.G. filter plus pipeline	930	390	248	Approx. 13,000	7,300	3.52	2.84	0.041	99.75	0.550
3	Hot Blast	17.6	Waste gas cleaning, open glass fabric filter	3-6	1,830	480	*	65,000	38,000	*	0.35	*	99.0	--

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* No data available.

** Before cleaned gas measuring point after fabric cleaner, approximately 1,200 scfm false air was drawn in.

18.5.5 Wet Scrubbers

Various types of wet scrubbers are widely used for control of cupola emissions.[8] The SO_2 content of the cupola waste gases must be considered in designing a wet scrubber system. It is often overlooked that it is not sufficient to neutralize the scrubbing water to a pH value of 7 so that it enters the scrubber in a neutral state. An acidic reaction occurs after it contacts the cupola waste gases and a serious corrosion danger exists. The wash water thus should be adjusted to a pH of 9 so that in the gas washer itself the acidic range is not reached.

Although the wet-scrubber systems absorb some of the SO_2 from the waste gases, the odor of SO_2 may be more perceptible than with other collection systems because wet scrubbing lowers the temperature of the gases which causes a decrease in plume rise.[3] The carbon content of the dust makes wetting more difficult and thus puts higher requirements on wet scrubbers.

Wet scrubbers pose the problem of sludge removal and potential water pollution which must be taken into account in computing the cost of this type of collector.

Wet caps have been in common use on cupola gases but these only remove the coarser particles and are usually not adequate for compliance with local codes.

18.5.6 Dry Cyclones

Centrifugal dust collectors are used in many ways in the foundry industry. They can function satisfactorily up to temperatures over 800°F. They are used for cupola waste gases provided the fine grain proportion in the cupola dust is not too high. The collection efficiency may run 80-90%. However, the raw gas dust content and its particle size distribution should be determined by measurement to ascertain the efficiency that can be expected for any specific application.[3] The results of five tests on different installations using dry multiple cyclones are given in Table 18-5.[1]

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CHAPTER 19

SECONDARY NONFERROUS METALS INDUSTRY

19.1 INTRODUCTION

The secondary nonferrous smelting and refining industry comprises establishments primarily engaged in recovering nonferrous metals and alloys from scrap and dross. The secondary nonferrous industry, as used here, will include copper, lead, zinc, and aluminum recovery. Copper, including brass and bronze alloys, and lead production from secondary smelters account for about 50% of the yearly total production of these metals in the United States.5/

The nature of furnace operations in this industry is such that emissions vary widely during the cycle from charging the scrap to pouring the melt. Peak emission surges occur in nearly all the furnace operations. The principal emission from the secondary copper, lead, zinc, and aluminum industries is particulates--smoke, dust, and metallic fumes. Small amounts of sulfur oxide may also be evolved. Table 19-1 summarizes particulate emissions from the secondary nonferrous metals industry.

The production processes, particulate emission sources, particulate emission rates, effluent characteristics, and control practices and equipment for the secondary copper, lead, zinc, and aluminum industries are discussed in the following sections.

19.2 SECONDARY COPPER SMELTING AND REFINING

Obsolete domestic and industrial copper-bearing scrap are the basic raw materials for the secondary copper industry. The overall industry is composed of many groups, including dealers, collectors, foundries, ingot makers, and smelters. Scrap as received is frequently not clean and may contain any number of metallic and nonmetallic impurities. These impurities can be removed by mechanical methods, heat methods, or gravity separation.1/

A number of types of furnaces are used for the melting, smelting, refining, and alloying of the processed scrap metal. Reverberatory, rotary, or crucible furnaces are used, depending on the size of the melt and the desired alloy. Processing is essentially the same in any furnace except for the differences in the types of alloy being handled. Crucible furnaces are usually much smaller, whether electric or nonelectric, and are used principally for small quantities of special-purpose alloys.1/

19.2.1 Emission Sources and Rates

Emissions that may contribute to atmospheric pollution are released from various operations in secondary copper smelting and refining. Included are the handling and concentrating of raw materials (i.e., scoop processing); the burning of oil, grease and insulating materials; the refining and concentrating of low-grade scrap and metallurgical wastes in a blast furnace; plus the firing up, charging, alloying, and pouring operations connected with the furnace. The types and ranges of emissions depend on factors such as fuel, composition, and melting temperature of the alloys, types of furnaces, and operating factors such as methods of charging, melting, refining, removing slag, adding alloy metals, and pouring.

Individual emission sources in the various operations mentioned in the preceding paragraph are discussed in more detail in the following sections.

19.2.1.1 Scrap Processing: The mechanical methods of processing scrap cause few or no pollutant problems, while pyrometallurgical processes all create air pollutants to some degree.

Sweating is carried out at medium temperatures to remove low-melting-point metals such as lead, solder, and babbit metal from radiators and other scrap. Metal fume losses are very low, but fume and combustion products of antifreeze residues, soldering salts, and hose connections may be released.2/

Burning also removes insulation that was not mechanically stripped from wire or cable. Source tests indicate that uncontrolled emissions can be a dense black smoke containing particulate matter in concentrations as large as 29 grains/scf at 12% CO_2.3/

A heated rotary kiln is often used to vaporize excess cutting fluids from machine shop chips or borings. This drying operation creates considerable amounts of hydrocarbons. The nature of the combustion process that eliminates these hydrocarbons will determine whether fumes and soot escape or whether emissions are clean and fully oxidized. The vaporized fumes must be burned in afterburners to oxidize the hydrocarbons and prevent air pollution.

The blast furnace (or cupola) produces a concentrated product called "black copper" or "cupola melt" from low-grade materials such as slag and skimmings. The product actually has variable proportions of copper, tin, lead, zinc, nickel, and other metals. The charge is introduced at the top of a vertical furnace, along with coke for fuel and a reducing agent, plus limestone or other materials for fluxing. Slag and concentrated alloy are tapped near the bottom of the furnace. Slag is often tapped continuously while metal is obtained at intervals. A large volume of air is introduced through tuyeres spaced around the periphery of the furnace. Temperatures in the smelting zone are sufficient to reduce oxides to molten metal. These temperatures drop rapidly while the gas rises through the charge material to the top of the furnace. The particulate matter and gases emitted from the blast furnace are likely to be rather variable because of the large variety of scrap, slag, skimmings, and spills that are processed.1/

19.2.1.2 Smelting and Refining: Direct-fired (or open-flame) furnaces such as reverberatory and rotary types will produce larger concentrations of zinc oxide fume than will indirect-fired furnaces such as crucibles and electric-induction furnaces.

Since the hot, high-velocity combustion gases come into direct contact with the metals in the charge, metal losses are high when there is an appreciable proportion of zinc in the alloy. The direct-fired type of furnace is often more difficult to hood effectively. Except for the physical arrangements, however, the actual smelting and refining that produce high-quality ingots are similar in both direct-fired and indirect-fired furnaces.

A number of factors in furnace operation can affect the type and quantity of emissions. Among these are the type of fuel used, control of air-fuel ratios, control of temperatures, the order of adding metals to the furnace, provision of proper slag cover, and good housekeeping in the furnace area.1/

19.2.1.2.1 Heating: Fuel used in the various furnaces can have important effects on the types of emissions from the plants. Electric furnaces do not add any objectionable emissions and, what is more important, they do not have the effects of hot gases sweeping across the surface of the melt. Indirectly heated furnaces also avoid this sweeping effect.

The choice of oil or gas as a fuel is usually made on the basis of lowest cost for a given heat content, but gas is often more trouble-free, both in minimizing pollution and in maintaining proper combustion conditions. When oil is used, very careful control of the air-fuel ratio is necessary to reduce pollutants such as soot, smoke, and unburned fuel particles to a minimum.

19.2.1.2.2 Charging: The type and condition of the scrap raw material are factors that may affect the amount and character of each emission. Scrap that is oily, greasy, or dirty may have these contaminants removed by preliminary treatment, or the operations may be done directly in the main furnaces. In either case considerable smoke emissions are apt to occur. With combustion there will be emissions of the normal products of combustion plus unburned hydrocarbons, fly ash, and dust in the stack gases. When the scrap material being used has relatively large proportions of low-volatility constituents such as zinc, metallic oxide fume will be in the stack gases of the furnaces.

During the charging cycle, emissions are also dependent upon factors such as location of the charging doors, the percentage of volatile alloy constituents (principally zinc), and upon whether the entire charge is made at the beginning of the heat or at intervals during the melting stage. Overhead charging doors in reverberatory furnaces will permit large losses of hot gases, fly ash, and fume into the plant when charges are loaded at intervals during the heat. Effective hooding of overhead charge doors poses difficult problems because of the necessity of providing access for loading equipment into the space between the charge door and the hood. End and side doors are not as vulnerable to the loss of furnace gases, especially end doors that load the charge in the direction of the induced flow of the furnace gases.

Some of the greatest air pollution problems occur during charging. It is physically difficult to place the entire charge into the furnace at one time. Later charges are, therefore, added to molten metal, and the combustible materials (and plain dirt) are emitted in tremendous bursts that are almost impossible to burn completely or even to contain within the capacity of the collection system.1/

19.2.1.2.3 Melting: After material is charged, all doors and openings of the furnace are closed. Burners are set to maximum efficiency for fastest melt-down and superheating of the molten metal. Supplemental oxygen may be used at this time. Excessive fuming may occur whenever zinc is present or combustible contaminants are present in the charge. The latter may include items such as grease, oils, and rubber. Much of the combustible emissions may be controlled by proper draft regulation and burner setting. The lack of uniformity in scrap, however, makes this control difficult.

19.2.1.2.4 Refining: Refining, a chemical process of purification, is that cycle of the heat in which impurities and other constituents of the charge, present in excess of specifications, are reduced or removed. Many different processes are employed to bring the composition of the melted scrap within permissible limits. Refining methods vary with the type of furnace, the type of alloy being produced, the condition or availability of different types of scrap in the charge, and the experience and opinions of the personnel involved.

The chemicals used in refining, commonly termed fluxes, may be gaseous, liquid, or solid. By far the most extensively used gas for refining is compressed air (oxygen). Blowing air into the molten bath of metal causes a selective oxidation of metals in accordance with their position in the electromotive series. Iron, manganese, silicon, and aluminum are high in the series and are, therefore, oxidized in preference to copper, tin, and other metals. Part of the zinc is oxidized, but this is an unavoidable loss. Below certain concentrations, the undesirable metals are oxidized simultaneously. Solid fluxes as a whole do not contribute to air pollution, except in releasing impurities that must be removed from the alloy in one way or another. Flux covers, which are eventually skimmed off, have a generally beneficial effect on the quality of stack emissions by preventing excessive volatilization losses. Some of the more common fluxes are broken glass, charcoal, borax, sand, limestone, iron scale, soda ash, and caustic soda.1/

19.2.1.2.5 Alloying: Modification of the alloy during the heat by addition of virgin metal or specialized scrap may lead to an increase in fume emission. Excessive formation of fume becomes greater as the percentage of volatile constituents increases. Owing to its very low boiling point, zinc is the most serious problem.

19.2.1.2.6 Pouring: Physical methods of pouring the molten alloy into molds vary. The furnaces may be tapped directly to a moving, automatically controlled mold line, the alloy sometimes filling one or more molds at once and then being shut off while a new set of molds moves into position on the endless conveyor. In other variations, the metal is tapped from the furnace into a ladle, which should have a slag cover, especially for high-zinc alloys. The molten alloy is then moved to a mold line, which may be movable or stationary.

Metal-oxide fumes are produced as the hot molten metal is poured through the air, even over these short distances. Other dusts may be produced, depending upon the type of linings or coverings associated with the mold as it is filled with hot molten metal.

19.2.1.3 Summary of Emission Rates: Table 19-1 summarizes emission rate data for the various sources in the secondary copper-production cycle. Materials-preparation processes account for about 70% of the particulate emissions. The wire-burning step of the materials preparation emits about 41,000 tons/year. Emissions from smelting and refining furnaces total about 17,000 tons/year.

TABLE 19-1

PARTICULATE EMISSIONS
SECONDARY NONFERROUS METALS

Source	Quantity of Material	Emission Factor	Efficiency of Control C_c	Application of Control C_t	Net Control $C_c \cdot C_t$	Emission tons/yr
I. Copper						
A. Materials Preparation						
1. Wire burning	300,000 tons insulated wire	275 lb/ton				41,000
2. Sweating furnaces	64,000 tons, auto radiators	15	0.95	0.20	0.19	400
3. Blast furnaces	287,000 tons, scrap and residue	50 lb/ton scrap	0.90	0.75	0.68	2,300
B. Smelting and Refining	1,170,000 tons scrap					
1. In secondary smelters, etc.						
(a) charge		30 lb/ton charge				
(b) refine		39				
(c) pour		0.6				
		70	0.95	0.60	0.57	17,000
		Total from Secondary Copper				60,700
II. Aluminum						
A. Sweating Furnaces	500,000 tons of scrap	32 lb/ton scrap	0.95	0.20	0.19	6,000
B. Refining Furnaces	1,015,000 tons scrap					
1. Reverberatory		4 lb/ton scrap	0.95	0.60	0.57	900
2. Pot (crucible)		2 lb/ton scrap	--	--	--	--
3. Induction		--	--	--	--	--
C. Fluxing	136,000 tons Cl used	1,000 lb/ton Cl used	--	--	0.25	51,000
D. Dross Processing						
1. Hot process						
2. Milling process						
		Total from Secondary Aluminum				57,900
III. Lead Furnaces						
A. Pot	53,000 tons scrap	0.8 lb/ton scrap	0.95	0.95	0.90	< 100
B. Blast Furnace	119,000 tons scrap	190 " "	0.95	0.95	0.90	1,000
C. Reverberatory		130 " "	--	--	--	--
D. Rotary Reverberatory		70 " "	--	--	--	--
Average, reverberatory	554,000 tons scrap	100 lb/ton scrap	0.95	0.95	0.90	3,000
		Total from Secondary Lead				4,000
IV. Zinc						
A. Sweating						
1. Metallic scrap	52,000 tons scrap	12 lb/ton charge	0.95	0.20	0.19	300
2. Residual scrap	210,000 tons scrap	30	0.95	0.20	0.19	2,600
B. Distillation Furnace	233,000 tons Zn recovered					
1. Distillation retort		47 lb/ton Zn				
2. Muffle		45 lb/ton Zn				
Average, distillation furnaces		45 lb/ton Zn	0.95	0.60	0.57	2,200
		Total from Secondary Zinc				5,100
		Total from Secondary Nonferrous Metals				127,700

19.2.2 Characteristics of Effluents

The chemical and physical properties of effluents from secondary copper production are summarized in Table 19-2. The metallic fumes emitted from the smelting and refining furnace are submicron in size. The fumes also readily agglomerate, and the exhaust plume is usually opaque.

19.2.3 Control Practices and Equipment

19.2.3.1 General Control Practice: Air pollution control practices for the secondary nonferrous metals industry were investigated in a 1969 study done by the U. S. Department of Commerce.6/ While the study did not pertain solely to secondary copper, the results will be summarized in this section for convenience.

19.2.3.1.1 Baghouses: Most smelters observed had completely dry collection systems. Water quenching was not used; instead, outside air was mixed with the hot flue gases.6/ This latter procedure has the drawback of requiring a design to accommodate not only the furnace flue gas, but also the volume of outside air injected into the system. In addition, there is considerable fire hazard. The hot flue gases are often deficient in free oxygen, and if the furnace charges contain oily scrap or other combustible materials, admission of oxygen-rich outside air can cause low-order explosions and fire.6/

Of the 23 plants considered in the Commerce Department study, eight had efficiently functioning dry baghouse systems. One had an equivalent system but used some water as a gas cooling spray before the baghouse. Most of these plants were brass or bronze ingot producers and lead smelters. In addition to baghouse systems, and at other plants, small modular baghouses of simple design are used to filter gases and in-plant air from ducted hoods over kettles, furnace charging doors, open hearths, and slag melt draw points.6/

19.2.3.1.2 Electrostatic precipitators: Electrostatic precipitators are used to clean furnace flue gases. This system of gas cleaning is efficient when properly designed and engineered for the individual plant. Collection efficiency drops when residence time is insufficient. Surges in furnace flue gas volume can easily cause too short a residence time unless equipment is designed for capacity to accommodate peak volumes and peak loading of flue gases. Efficiency is also temperature sensitive owing to the relation of temperature to resistivity.6/

TABLE 19-2

EFFLUENT CHARACTERISTICS - SECONDARY NONFERROUS METALS*

A. Particulate (Part I)

Source	Particle Size	Solids Loading	Chemical Composition	Particle Density	Electrical Resistivity	Moisture Content	Toxicity
Secondary Non-ferrous Metals							
I. Copper							
A. Foundries	Metallic fume 0.03-0.5 (unagglomerated)	1-4	Typical constituents: ZnO, PbO, C, fly ash, and a variety of secondary constituents representing charge composition. For specific alloys the following are representative. ZnO and PbO distributions: Copper-Brass Alloy ZnO: 14-96 Avg. - 59 PbO: 5-29 Avg. - 15.5 Copper-Nickel Alloys ZnO: 54-87 Avg. - 67 Copper-Lead Alloys ZnO: 5-8 Avg. - 6-5 PbO: 51-62 Avg. - 57 Secondary Constituents: Tin, cadmium, copper, silica, and carbon		See Table 19-3 for fuller statement of interrelated variables		Zn - 15 Pb - 0.15
B. Ingot Production	Metallic fume 0.03-0.5 (unagglomerated)	1-20 (high values when compressed air is injected into bath)	Typical composition range of baghouse catch: Zn: 45-77; Pb: 1-12; Sn: 0.3-2; Cu: 0.05-1.0; S: 0.1-0.7.				
II. Lead	Very fine; typical range: 0.07-0.4 Mean size; 0.3 (unagglomerated)	2-12 (blast furnace) 1-6 (reverberatory furnace)	PbO, SnO, ZnO, tar, fly ash, coke dust, sulfates, sulfides				ZnO - 15
III. Zinc							
A. Sweat Furnace Flux Phase					See Figures 19-1 and 19-2 for details		
1. Kettle furnace	0.03-0.5 (unagglomerated)	0.8-1	Zn, Cl_2, ZnO NH_4Cl, Al_2O_3 Oxides of Mg, Sn, Ni, Si, Ca, Na (dependent on charge composition and quantity of flux)				
2. Reverberatory furnace	No detailed data; probably about 1 µ	0.8-1	Similar to kettle furnace				
IV. Aluminum	100 < 2 (cryolite fluxing, electron photomicrograph) 100 < 1 (chlorinating process)	0.1-2.0	Highly variable, may contain Al_2O_3, $AlCl_3$, NaCl, fluorides, oxides of alkali metals				Toxic due to fluorides and chlorides

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* See Coding Key, Table 5-1, Chapter 5, page 45, for units for individual effluent properties.

TABLE 19-2 (Continued)

A. Particulate (Part II)

Source	Solubility	Wettability	Hygroscopic Characteristics	Flammability or Explosive Limits	Handling Characteristics	Optical Properties	Odor
Secondary Non-ferrous Metals							
1. Copper -	s. sl. alk.		Absorbs water, tends to lump and/or mass		Agglomerates, cohesive		
2. Lead	"	Difficult to wet			" "		
3. Zinc	"	" "			" "		
4. Aluminum					Abrasive, corrosive		

B. Carrier Gas

Source	Flow Rate	Temperature	Moisture Content	Chemical Composition	Toxicity	Corrosivity	Odor	Flammability or Explosive Limits	Optical Properties
Secondary Non-ferrous Metals									
I. Copper									
A. Foundries Alloy Type									
1. Brass									
a. Oscillating barrel furnace	(a) 3.1* (b) 0.420*	270-330		Typical composition (similar for all furnace types) Furnace Outlet CO_2: 10.6-14 O_2: 1.1-4.9 CO: 0-3.3 N_2: balance SO_2: trace Stack CO_2: 0.4-2.4 O_2: 16.8-19.8 CO: 0 N_2: balance SO_2: trace	SO_2 - 5, irritant				
b. Rotating barrel furnace	(a) 7.6* (b) 0.390*	560							
c. Tilting-kettle furnace	(a) 18.7-22.2* (b) 0.996-1.344*	360-400							
d. Crucible	(a) 3-3.1* (b) 0.34-0.4*	400-450							
2. Nickel									
a. Pit crucible	(a) 2-3.4* (b) 0.5-0.8*	197-225							
b. Electric arc	(a) 0.725* (b) 0.134*	107							
3. Lead									
a. Tilting furnace	(a) 2.1-2.5* (b) 0.38-0.5*	315-362							
B. Ingot Production									
1. Reverberatory furnace	(a) 5.6-17.6	450-650; 200-220 at baghouse inlet	3.1-24	Stack CO_2: 0.34-1.4 Avg.: 0.57 O_2: 17.8-19.1 Avg.: 18.3 N_2: balance CO: 7.7-42.2 ppm Avg.: 22.7 ppm SO_2: < 1 ppm Hydrocarbons: 0.02-0.05 ppm Halogens: < 1 ppm NO_x: < 1 ppm H_2S: < 1 ppm					

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* Actual cubic feet.

TABLE 19-2 (Concluded)

B. Carrier Gas (Concluded)

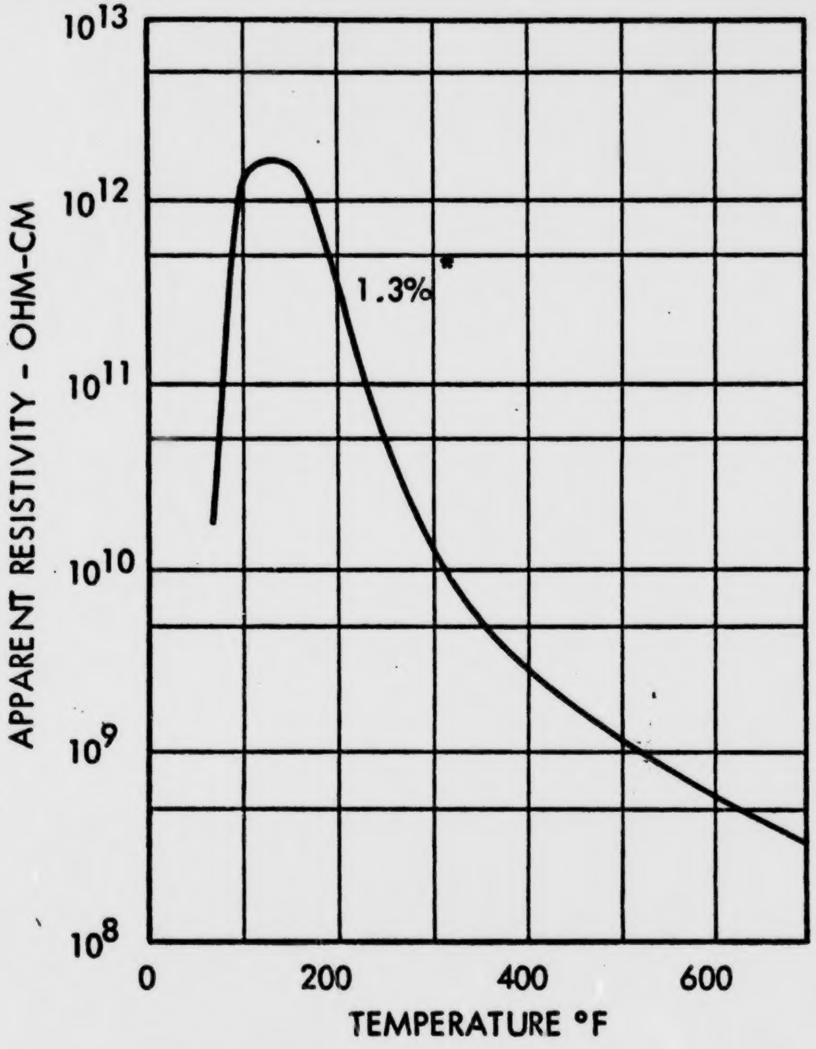
Source	Flow Rate	Temperature	Moisture Content	Chemical Composition	Toxicity	Corrosivity	Odor	Flammability or Explosive Limits	Optical Properties
2. Rotary furnace	(a) 11.4-36.7		1.7-2.3	Stack CO_2: 0.14-1.11 Avg.: 0.51 O_2: 18-18.5 Avg.: 18.2 N_2: balance CO: 6.9-10.8 ppm Avg.: 8.4 SO_2: 10 ppm Hydrocarbons: 0.16-0.37 ppm Halogens: < 1 ppm NO_x: $\leq$ 1 ppm H_2S: < 1 ppm					
3. Cupola	(a) 13.2-37	145-200 at bag-house inlet	1.1-2.7	Stack CO_2: 0.5-1.4 Avg.: 0.8 O_2: 18.9-19.4 Avg.: 19.2 N_2: balance CO: 1100-1575 ppm Avg.: 1258 ppm SO_2: 1 ppm NO_x: < 1 ppm H_2S: < 1 ppm Halogens: < 1 ppm					
II. Lead	(a) 2.1 (one blast furnace) 3.1 (one reverberatory furnace) 2.1-2.5 (two crucible furnaces)	500 (blast) 950 (reverberatory) 315-362		CO_2, CO, O_2, N_2, SO_2, H_2O	SO_2 - 5, irritant CO - 100				
III. Zinc									
A. Sweat Furnace Flux Phase									
1. Kettle furnace	(a) 2-16 (b) 185-222	105-195		Approximate O_2:21 N_2:78					
2. Reverberatory furnace	(a) 7-8 (two furnaces) (b) 400-800	190	4.5	Typical CO_2:2.4 H_2O:4.5 N_2:76.6 O_2:15.8					
IV. Aluminum									
1. Reverberatory furnace	(a) 1-9 (b) 0.1	200-1450		Typical Orsat CO_2:6.8 O_2:8.6 CO:0.02 N_2:77.3 H_2O:7.3 Trace SO_2	SO_2 - 5 irritant CO - 100				

TABLE 19-3

ELECTRICAL RESISTIVITY OF COLLECTED BRONZE FUME[12]

(Laboratory Measurements)

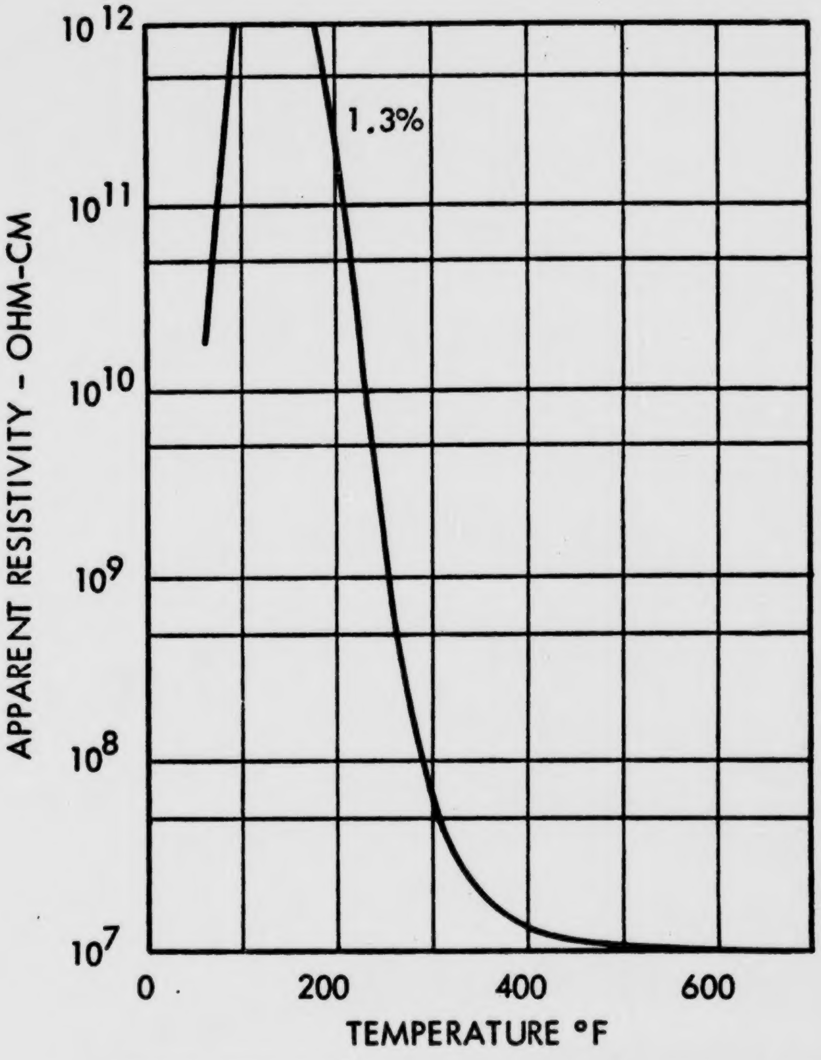
Water Content (%)	Temperature (°F)	Resistivity (ohm-cm)
6	280	4×10^{13}
6	330	1.8×10^{13}
6	380	5×10^{12}
6	430	1.8×10^{12}
6	480	5×10



* Figure shows percent water vapor by volume.

Figure 19-1 - Apparent Resistivity of Zinc Fume 11/ from Slag Fuming Plant

As function of temperature at 1.3% moisture content by volume



* Figure shows percent water vapor by volume.

Figure 19-2 - Apparent Resistivity of Zinc Fume 11/ from Melting Plant

As function of temperature at 1.3% moisture content by volume

19.2.3.1.3 Wet scrubbers: Five of the 23 plants considered in the Commerce Department study had a wet scrubber as the major component of their flue gas cleaning system. Three were aluminum alloy ingot producers, one a zinc remelt alloy shop, and one a producer of brass and bronze ingots. The wet scrubbers are best applicable to cleaning furnace gases with low particulate grain loading but high loading of soluble gases and mists such as hydrochloric and sulfuric acids.6/

The packed tower is a popular wet-scrubber design in use in the secondary nonferrous metals industry, particularly in aluminum plants where chlorine is used to purge magnesium from the furnace melt. The scrubber towers may be constructed by using a steel shell suitably lined with rubber or acid-resistant brick to isolate the shell from the highly corrosive gases.

19.2.3.1.4 Incinerators and afterburners: Most grades of scrap metal require incineration of attached foreign nonmetallic constituents before smelting and refining. Insulation on wire is a major contaminant which is usually removed by incineration. Generally, the incinerator operating temperature must be maintained high enough to either burn or volatilize the contaminant and low enough to prevent excessive oxidation of the metal.6/

Copper wire scrap, with its various kinds of insulation, sometimes presents incineration problems. Mechanical stripping of fine gauge wire is being done at some plants, thereby obviating the need for incineration.

Burning of copper wire to free the copper from insulation sheaths of plastic, rubber or paper is most efficiently done in a two-stage incinerator. In the primary chamber the temperature is maintained hot enough to support combustion of the insulation but low enough to prevent excessive oxidation of copper. The only partly burned hydrocarbons escape in a sooty gas stream into a secondary chamber equipped with an afterburner. Very hot temperatures and an excess of oxygen convert the hydrocarbons to CO_2 and H_2O.

Polyvinyl chloride-coated wire presents an incineration problem. The PVC is fire resistant and it resists normal incineration methods. Furthermore, combustion of PVC liberates chlorine which combines either with water vapor to form hydrochloric acid or with metallic elements in the scrap to form harmful metal chlorides. Phthalic anhydride is also generated by burning polyvinyl chloride. To prevent the escape of noxious components through the flue, combustion gases must be passed from the afterburner chamber through an additional packed wet scrubber. The resulting effluent is neutralized with sodium hydroxide or other chemical base. Obviously, disposition of the scrubber effluent could cause water pollution problems.6/

Some other coatings on scrap metal have compositions that require special caution during incineration. Teflon contains fluorine, and unregulated burning of Teflon-coated scrap releases toxic gaseous fluorides. A source of white smoke is silicon rubber, which burns with release of SiO_2.[7]

One of the deficiencies of air pollution control equipment in secondary nonferrous metals plants is in the afterburner units on incinerators. Many do not have the precise temperature control needed for complete combustion, and it seems doubtful that the design features insure adequate mixing of the hot gases with proper quantities of oxygen from the air. Another possible fault in many afterburner designs is the failure to provide sufficient retention time of the hot gases for combustion in the area of appropriate temperature and oxygen availability.[6]

Experimental testing of a Peabody scrubber operating at a total gas pressure drop of 43 in. w.g. showed dust collection efficiency of 94.5% for an incinerator burning insulated copper wire (equipped with an afterburner).[7]

19.2.3.2 Specific Control Practices for Secondary Copper: The principal source of atmospheric emissions in the brass- and bronze-ingot industry is the refining furnace. The exit gas from the furnace may contain the normal combustion products such as fly ash, etc. Because zinc is a major low-boiling-point constituent, appreciable amounts of zinc oxide are normally present in the exit gases also.

Fumes and dust from the blast furnace or cupola are similar to those from ingot furnaces. A common practice is to direct these fumes to the same collection device used for ingot furnace emissions. A dry inertial collector frequently precedes a baghouse in order to remove the large abrasive particles, but high-efficiency particulate collection equipment is necessary to remove the fine particulate.[1]

Hooding a rotary-tilting-type reverberatory furnace for complete capture of fumes is difficult, and complete collection is seldom achieved. These furnaces are undoubtedly the most difficult type of brass furnace to control.

Capturing the dust-laden gases generated during charging and pouring operations is particularly difficult. One reverberatory furnace installation, using top charging, is covered by a 12 ft. x 24 ft. hood with an air intake capacity of nearly 40,000 cfm. This size is still sometimes insufficient to capture all the emissions.[1]

The only air pollution control equipment to receive general acceptance in the brass- and bronze-ingot industry is the baghouse collector. Recent NAPCA data indicate that the concentration of particulate matter escaping baghouses ranges from 0.006 to 0.036 grain/scf, and operating efficiencies were generally between 95 and 99.6%. Filter ratios of 2.0 to 2.7 cfm/sq ft and pressure drops of 2 to 6 in. of water are usually encountered.[1]

The cooling of gases prior to filtration is a major engineering design consideration to prevent burning of the bags and to maintain the gas above the condensation temperature.[1] The gases leaving a reverberatory furnace may be 100° to 200°F hotter than the molten metal and must be cooled before reaching the filter cloth. Direct cooling, by spraying water into the hot combustion gases, is not generally practiced because (1) corrosion of ductwork and equipment increases; (2) vaporized water increases exhaust gas volumes; and (3) temperature of the gases in the baghouse must be kept above the dewpoint. Water-jacketed coolers and radiation convection coolers are used to cool the gases without water-injected sprays.[8]

The baghouse designs must take into account the variations in temperature, gas volume and emissions during the entire refining cycle so that plant operations may be continued at full capacity under any conditions. The baghouse should have a sufficient number of compartments so that one compartment can be bypassed while the others continue to operate and thus permit replacement of broken bags or allow for unusual cleaning requirements. The use of four compartments normally satisfies this requirement.[1] Maintaining duct velocities of 2,500 - 3,000 ft/min is desirable to minimize buildup of dusts in the duct.

Table 19-4 shows the results of tests performed on baghouses venting brass furnaces. Larger baghouses are necessary for crucible gas-fired furnaces because of the heat and volume of the products of combustion from the gas burners.[8] A summary of information on baghouses for brass and bronze furnaces is given in Table 19-5.[1]

While baghouses have been found to be the most successful device for collecting large quantities of zinc oxide, there has been no universal acceptance of a particular filter fabric. These fabrics must be able to withstand fairly high temperatures in spite of the dilution and precooling of gases. They must also withstand considerable physical abuse and vibration. The use of glass fabric in baghouses allows higher temperature operation (550°F continuous) than the use of synthetic organic fabrics. However, the inherently low mechanical strength of glass fabric requires cleaning methods of a lower intensity than the mechanical shaking methods used with the synthetics.[1]

TABLE 19-4

BRASS-MELTING FURNACE AND BAGHOUSE COLLECTOR DATA[a]

Case	A	B	C
Furnace data			
Type of furnace	Crucible	Crucible	Low-frequency induction
Fuel used	Gas	Gas	Electric
Metal melted	Yellow brass	Red brass	Red brass
Composition of metal melted, %			
Copper	70.6	85.9	82.9
Zinc	24.8	3.8	3.5
Tin	0.5	4.6	4.6
Lead	3.3	4.4	8.4
Other	0.8	1.3	0.6
Melting rate, lb/hr	388	343	1,600
Pouring temperature, °F	2,160	2,350	2,300
Slag cover thickness, in.	1/2	1/2	3/4
Slag cover material	Glass	Glass	Charcoal
Baghouse collector data			
Volume of gases, cfm	9,500	9,700	1,140
Type of baghouse	Sectional tubular	Sectional tubular	Sectional tubular
Filter material	Orlon	Orlon	Orlon
Filter area, sq. ft.	3,836	3,836	400
Filter velocity, ft/min	2.47	2.53	2.85
Inlet fume emission rate, lb/hr	2.55	1.08	2.2[a]
Outlet fume emission rate, lb/hr	0.16	0.04	0.086
Collection efficiency, %	93.7	96.2	96.0

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[a] Includes pouring and charging operations.

TABLE 19-5

BAGHOUSE INFORMATION SUMMARY - BRASS AND BRONZE INGOT INSTITUTE[1]

Size of Baghouse, cfm	No. of Bags - Diameter, In.	Bag Material	Type and Size of Furnaces Vented to the Baghouse	Material Collected in Baghouses				Frequency of Bag Replacement
				Lb/Ton Charged	Lb/Ton Produced	% ZnO	% PbO	
2 units - 24,000 each (design) 18,000 (actual)	1,944 - 6	Orlon and dacron	2 Rev-60 tons/ht each 2 Rot-2 tons/ht each 4 Elec-1 at 4 tons/ht 3 at 1/2 ton/ht	58	67	63	8	18 months
3 units - 13,000 each (design)	2,268 - 6	Dacron	2 Rev-60 tons/ht each 2 Rot-4 tons/ht each 1 Cupola	60	68	78	7.5	10 to 15 months
10,000 cfm (design)	100 - 15	Glass	1 Radiator sweater					
27,500 (design) 18,000 (actual)	324 - 8	Orlon and dacron	4 Rev-60 tons/ht each					4 months
30,000 (design 29,000 (actual)	528 - 8	Orlon and dacron	3 Rot-4 tons/ht each	60[a]	88[a]	72[a]	8[a]	6 months
	320 - 5	Orlon	No flow diagram provided; equipment layout not ascertainable					12 months
	900 - 8	Orlon	3 Rev-30-75 tons/ht each 1 Rot-10 tons/ht	55	NR	58	3	12 months
Square-filter type 26,000 (design)	400 - 10	Orlon	Cupola 2 Rev-80 tons/ht each 5 Rot-7-1/2-35 tons/ht each	NR	NR	65	5 to 6	6 months
Multiple-bag type	1,500 - 6	Orlon	No flow diagram provided; layout of equipment not ascertainable					
Custom-designed 12,500 cfm/chamber (No. of chambers not reported)	416 - 18	Wool	3 Rev-2-75 tons/ht each 3 Rot-2.7 tons/ht each 3 Crucible-0.25 tons/ht each 1 Elec-3 tons/ht 1 Cupola-no tonnage reported	NR	NR	55	NR	51 months
30,000 (design and actual)	1,200 - 5	Orlon	3 Rev-2-30 tons/ht each 1 - 12 tons/ht each					
50,000 (design and actual)	800 - 8	Orlon	1 Slug-15-25 tons/ht each	NR	NR	NR	NR	12 months

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[a] Not stipulated if these figures are total figures for the three units.

Electrostatic precipitators and wet scrubbers have not proved entirely satisfactory on lead and zinc fumes from brass and bronze furnaces. Lead oxide in particular is difficult to collect by electrostatic precipitators because of its relatively high resistivity. In addition, high-voltage precipitators have not been available in small units suitable for small nonferrous foundry use and the first cost may, moreover, be prohibitive.8/

A number of dynamic and static scrubbers have been tested on brass furnaces and all have been found unsatisfactory. The scrubbers failed to reduce the particulate matters sufficiently and opacity was excessive. These scrubbers were replaced by baghouses.8/

The Commerce Department study also reported cost data for air pollution control in the secondary nonferrous metals industry. The average operating cost, for three dissimilar systems, was about $0.80/year per cfm of capacity and ranged from $0.36 to $1.07/year per cfm. Since some larger plants have air-cleaning equipment with a capacity to treat 150,000 cfm, their associated costs of servicing and maintaining this equipment could be as much as $120,000/year.6/

The cost of air pollution control as computed in the Commerce Department study of baghouse systems, shown in Table 19-6, averaged about 3/4% of the value of annual shipments. The study indicated that these installations and operating costs may have the effect of reducing net after-tax profits by 8 to 10%. A breakdown of cost findings is shown in Tables 19-7, 19-8 and 19-9.6/

The costs reported in the Commerce Department study6/ are much higher than the general cost figures presented in Appendix A. For example, the installed cost for a baghouse ranges from $2.66 to $8.33/acfm as given in Table 19-8. However, Appendix A indicates that the average installed cost of a baghouse should be about $2.00/acfm and the highest expected cost should not exceed $3.00/acfm. Also, the operating (and maintenance) costs shown in Table 19-9 range from $0.36 to $1.07/acfm which is three to ten times higher than would be expected on the basis of cost equations in Appendix A.

Other data available on air pollution costs at brass and bronze smelters indicate a broad range for installed costs. It is reported that a cost of $5.00 per cfm might be "typical" for an installed system, the baghouse itself representing about 40% of the total cost.1/ This installed cost agrees with cost data shown in Table 19-8 but, as previously discussed, this is considerably higher than the general cost figures in Appendix A.

TABLE 19-6

ANNUAL COST OF AIR POLLUTION CONTROL SYSTEMS[6]

(Secondary Nonferrous Metals Industry)

	5-Year Depreciation Basis	7-Year Depreciation Basis
Annual cost as percentage of annual value of shipments	%	%
Mean		
Installed equipment	0.46	0.33
Operating and maintenance	0.44	0.44
TOTAL	0.90	0.77
Median		
Installed equipment	0.52	0.37
Operating and maintenance	0.43	0.43
TOTAL	0.95	0.80
Annual per cubic-foot-per-minute (cfm) of gas-cleaning capacity (dollars)	$	$
Mean		
Installed equipment	0.86	0.61
Operating and maintenance	0.76	0.76
TOTAL	1.62	1.37
Median		
Installed equipment	0.80	0.60
Operating and maintenance	0.88	0.88
TOTAL	1.68	1.48

Source: 1968 BDSA survey interview of six plants with installed dry baghouse systems.

TABLE 19-7

INSTALLED COSTS OF GAS-CLEANING EQUIPMENT SYSTEMS, BY TYPE OF SMELTER[6]

	Cents/Pound of Annual Metal Production			Cents/Dollar of Annual Metal Shipments			Dollars/Cubic-Foot-Per-Minute of Capacity to Treat Smelter Flue Gases		
	High	Low	Average	High	Low	Average	High	Low	Average
All nonferrous smelters:									
11 plants	2.03	0.30	0.97	6.60	0.58	2.67	--	--	--
9 plants	--	--	--	--	--	--	8.33	2.50	4.66
8 plants[a]	--	--	--	3.16	1.25	2.14	--	--	--
Brass and bronze ingot makers:									
5 plants	1.53	0.50	0.95	3.06	1.25	2.07	--	--	--
4 plants	--	--	--	--	--	--	8.33	4.09	6.23
Copper producers:									
2 plants	--	--	--	--	--	2.83	--	--	--
Aluminum ingot producer									
1 plant	--	--	1.35	--	--	--	--	--	--
Lead smelters:									
2 plants	0.72	0.30	0.51	2.00	1.64	1.82	4.00	3.04	3.52
Zinc alloy producer:									
1 plant	--	--	--	--	--	--	--	--	2.50

-- Not available, not compiled separately, or not applicable.

[a] Excludes 2 highest and 1 lowest of 11 plants.

TABLE 19-8

INSTALLED COSTS OF GAS-CLEANING EQUIPMENT SYSTEMS, BY TYPE OF EQUIPMENT[6]

	Cents/Pound of Annual Metal Production			Cents/Dollar of Annual Metal Shipments			Dollars/Cubic-Foot-Per-Minute of Capacity to Treat Smelter Flue Gases		
	High	Low	Average	High	Low	Average	High	Low	Average
Baghouses:									
8 plants	2.03	0.50	1.07	--	--	--	--	--	--
7 plants	--	--	--	5.08	1.25	2.68	--	--	--
6 plants	--	--	--	--	--	--	8.33	2.66	5.09
Wet scrubbers:									
2 plants	1.35	0.67	1.01	--	--	--	--	--	--
1 plant	--	--	--	--	--	--	--	--	2.50
Combined baghouse and wet packed scrubber:									
1 plant	--	--	--	--	--	--	--	--	4.84
Electrostatic precipitators:									
2 plants	0.75	0.33	0.54	--	--	1.29	--	--	--
1 plant	--	--	--	--	--	--	--	--	4.09

-- Not available, not compiled separately, or not applicable.

TABLE 19-9

ANNUAL OPERATING COSTS OF GAS-CLEANING EQUIPMENT SYSTEMS, BY TYPE OF SMELTER[6]

	Cents/Pound of Metal Production			Dollars/Cubic-Foot-Per-Minute Cleaning Capacity		
	High	Low	Average	High	Low	Average
All nonferrous smelters:						
4 plants	0.28	0.05	0.12	--	--	--
3 plants	--	--	--	1.07	0.36	0.82
Brass and bronze ingot maker:						
1 plant	--	--	0.06	--	--	1.07
Lead smelter:						
1 plant	--	--	0.08	--	--	--
Multi-product smelters:						
2 plants	0.28	0.05	0.16	1.03	0.36	0.69

-- Not available, not compiled separately, or not applicable.

The costs of maintenance and operation of an air pollution control system have been reported by four smelters at $2.00, $0.90, $1.50, $1.73/ton of ingots produced. These costs include credits for value of byproduct material but the amortization of the capital cost of the system is not included.1/ These operating and maintenance costs are consistent with data in Table 19-8.6/ Again, this is much higher than would be expected based on general cost equations in Appendix A.

19.3 SECONDARY LEAD SMELTING AND REFINING

Reverberatory, blast, and pot furnaces are the three furnace types most commonly used in secondary lead smelting and refining. In addition to refining lead, most of the secondary refineries also produce lead oxide by the Barton process.

Various grades of lead metal along with the oxides are produced by the lead industry. The grade of product desired determines the type of equipment selected for its manufacture. The most common grades of lead produced are soft, semisoft, and hard. By starting with one of these grades and using accepted refining and alloying techniques, any special grade of lead or lead alloy can be made.

Soft lead may be designated as corroding, chemical, acid copper, or common desilverized lead. These four types are high-purity leads and are the products of the pot furnace after a considerable amount of refining has been done.

Semisoft lead is the product of the reverberatory-type furnace and usually contains from 0.3 to 0.4% antimony and up to 0.05% copper.

Hard lead is made in the blast furnace. A typical composition for hard lead is 5 to 12% antimony, 0.2 to 0.6% arsenic, 0.5 to 1.2% tin, 0.05 to 0.15% copper, and 0.001 to 0.01% nickel.3/

19.3.1 Emission Sources and Rates

The emission sources in secondary lead processing are similar to those discussed for secondary copper in Section 19.2.1. The main emission sources are the furnaces. The types and ranges of emissions from the furnaces will depend upon factors such as fuel, composition and melting temperature of the alloys, furnace type and operating factors. Individual emission sources in the various operations comprising the production cycle for secondary lead are discussed in more detail in the following sections.

19.3.1.1 Scrap Processing: The sweating of lead from scrap and dross is widely practiced. Junk automobile storage batteries supply most of the lead. In addition, lead-sheathed cable and wire, aircraft tooling dies, type-metal drosses, and lead dross and skims are also sweated. The rotary furnace, or sweating tube, is usually used when the material processed has a low percent of metal to be recovered. The reverberatory box-type furnace is usually used when the percent of metal recovered is high.

The discharge from a lead-sweating furnace may contain dust, fumes, smoke, sulfur compounds, and fly ash. This is particularly true when junk batteries are sweated. The battery groups and plates removed from the cases contain bits of asphaltic case, oil and grease around the terminals, sulfuric acid, lead sulfate, lead oxide, and wooden or glass-fiber plate separators. The organic contaminants burn poorly and the sulfur compounds release SO_2 and SO_3. The sulfur trioxide is particularly troublesome; when hydrolized to sulfuric acid, the acid mist is difficult to collect and is extremely corrosive.

Uncontrolled rotary lead-sweat furnaces emit excessively high quantities of air contaminants. Although the other types of scrap lead and drosses sweated in a reverberatory furnace are normally much less contaminated with organic matter and acid, high emission rates occur periodically.

Blast furnaces are used quite extensively in secondary smelting of lead storage batteries. The lead blast furnace or cupola is constructed similarly to those used in the ferrous industry. The materials forming the usual charge for the blast furnace, and a typical percentage composition, are 4.5% rerun slag, 4.5% scrap cast iron, 3% limestone, 5.5% coke, and 82.5% drosses, oxides, and reverberatory slags. Hard lead is charged into the cupola at the start of the operation to provide molten metal to fill the crucible. Normal charges are then added as the material melts down. The limestone and iron flux that floats on top of the molten lead retard its oxidation.3/

19.3.1.2 Remelting, Alloying, and Refining Processes: Pot-type furnaces are used for remelting, alloying and refining processes. Remelting is usually done in small pot furnaces, and the materials charged are usually alloys in the ingot form, which do not require any further processing. The quantity of air contaminants discharged from pot furnaces as a result of remelting, alloying, and refining is much less than that from reverberatory or blast furnaces.

A rather specialized phase of the industry is the production of lead oxide. Battery lead oxide, containing about 20% finely divided free lead, is usually produced by the Barton process. Molten lead is run by gravity from a melting pot into a kettle equipped with paddles. The paddles are rotated at about 150 rpm, rapidly agitating the molten lead, which is at a temperature of 700° to 900°F. Air is drawn through the kettles by fans located on the air outlet side of a baghouse. The lead oxide thus formed is conveyed pneumatically to the baghouse where it is collected and delivered by screw conveyor to storage.

Other lead oxides requiring additional processing but commonly made are red lead oxide (minimum, Pb_3O_4), used in the paint industry, and yellow lead oxide (litharage or massicot, PbO), used in the paint and ink industries.

Since the process requires the use of a baghouse to collect the product, and no other contaminants are discharged, no air pollution control system as such is needed.3/

19.3.1.3 Summary of Emission Rates: Table 19-1 summarizes emission rate data for the various sources in the secondary lead production cycle. Reverberatory furnaces account for nearly 75% (3,000 tons/year) of the particulate emissions in secondary lead production.

19.3.2 Effluent Characteristics

The chemical and physical properties of effluents from secondary lead production are summarized in Table 19-2. Metallic fumes emitted from the furnaces are submicron in size. Mean diameter is about 0.3 μ for unagglomerated material.

19.3.3 Control Practices and Equipment

In general, plants which are engaged in secondary lead smelting with either a blast furnace or a reverberatory furnace require an extensive system for air pollution control. The baghouse has long been considered as the most acceptable device for collecting lead fumes. The gas stream from the smelting furnaces is first passed through a series of water- or air-cooled tubes and then sent to a baghouse. The temperature of the baghouse must be kept fairly high to prevent the tar volatiles from condensing and blinding the bags. Lime is also added as the gas stream enters the baghouse to help prevent this blinding action. On leaving the baghouse the gas stream is discharged to the stack or in some instances further treated in an electrostatic precipitator in order to meet local ordinance requirements.6/

Reverberatory furnaces are used in lead-smelting operation. All the smoke and fume produced by this type of furnace must be collected and, since they are combined with the products of combustion, the entire volume emitted from the furnace must pass through the collector. Baghouses have been found to operate satisfactorily in this service. Provisions should be made to prevent sparks from contacting the filter cloth and temperature must be controlled by preceding the baghouse with radiant cooling ducts, water-jacketed cooling ducts or other suitable devices. Dacron bags are being used successfully in this service. Test results of secondary lead-smelting furnaces venting to a baghouse are shown in Table 19-10.8/

One of the largest secondary lead smelters in the U. S. uses fiberglass bags for fume collection, at higher than 400°F, of combined effluent from a reverberatory furnace and a lead blast furnace. The 400°F filtering temperature was desired to eliminate deposition of organic tars on the bags.9/

The control system for a lead blast furnace is similar to that employed for gray-iron cupola furnaces. Electrostatic precipitators are not used for economic reasons. Moreover, difficulties can be encountered in conditioning the particles to give them resistivity characteristics in the range that will allow efficient collection.8/

In the refining and alloying of secondary lead the air pollution problems are not as complex as those arising from the smelting of lead scrap. The fumes produced can be effectively treated by collecting them from the kettle hoods with a flow of around 200 cfm and passing them through a baghouse.10/

Available data on control equipment costs are presented along with the data for secondary copper in Section 19.2.3.2.

TABLE 19-10

DUST AND FUME EMISSIONS FROM A SECONDARY LEAD-SMELTING FURNACE[a]

Test Number	1	2
Furnace data		
Type of furnace	Reverberatory	Blast
Fuel used	Natural gas	Coke
Material charged	Battery groups	Battery groups, dross, slag
Process weight, lb/hr	2,500	2,670
Control equipment data		
Type of control equipment	Sectioned tubular baghouse[a]	Sectioned tubular baghouse[a]
Filter material	Dacron	Dacron
Filter area, sq. ft.	16,000	16,000
Filter velocity, ft/min at 327°F	0.98	0.98
Dust and fume data		
Gas flow rate, scfm		
Furnace outlet	3,060	2,170
Baghouse outlet	10,400[b]	13,000[b]
Gas temperature, °F		
Furnace outlet	951	500
Baghouse outlet	327	175
Concentration, grains/scf		
Furnace outlet	4.98	12.3
Baghouse outlet	0.013	0.035
Dust and fume emission, lb/hr		
Furnace outlet	130.5	229
Baghouse outlet	1.2	3.9
Baghouse efficiency, %	99.1	98.3
Baghouse catch, wt. %		
Particle size 0 to 1 μ	13.3	13.3
1 to 2	45.2	45.2
2 to 3	19.1	19.1
3 to 4	14.0	14.0
4 to 16	8.4	8.4
Sulfur compounds as SO_2, vol. %		
Baghouse outlet	0.104	0.03

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[a] The same baghouse alternately serves the reverberatory furnace and the blast furnace.

[b] Dilution air admitted to cool gas stream.

19.4 SECONDARY ZINC SMELTING AND REFINING

Zinc is melted in crucible, pot, kettle, reverberatory, or electric-induction furnaces for use in alloying, casting, and galvanizing and is reclaimed from higher melting point metals in sweat furnaces. Secondary refining of zinc is conducted in retort furnaces, which can also be used to manufacture zinc oxide by vaporizing and burning zinc in air.

19.4.1 Emission Sources and Rates

The emission sources in zinc recovery parallel those in the previous secondary processes, and the emissions are influenced by the fuel, composition and melting temperature of the alloys, furnace type, and operating factors. Individual emission sources in the various operations comprising the production cycle for secondary zinc are discussed in more detail in the following sections.

19.4.1.1 Scrap Processing: Zinc can be recovered by sweating in a rotary, reverberatory, or muffle furnace. Zinc-bearing materials fed to a sweating furnace usually consist of scrap die-cast products such as automobile grilles, license plate frames, and zinc skims and drosses.

Air contaminants released from a zinc-sweating furnace consist mainly of smoke and fumes. The smoke is generated by the incomplete combustion of the grease, rubber, plastics, and so forth contained in the material. Zinc fumes are negligible at low furnace temperatures, because zinc has a low vapor pressure even at 900°F. With elevated furnace temperatures, however, heavy fuming can result.[3]

19.4.1.2 Zinc Melting: The melting operation is essentially the same in all the different types of furnaces. Zinc to be melted may be in the form of ingots, castings, flashing, or scrap. Ingots, rejects, and heavy scrap are generally melted first to provide a molten bath to which light scrap and flashing are added. After sufficient metal has been melted, the bath is heated to the desired pouring temperature, which may vary from 800° to 1100°F. Before pouring, a flux is added and the batch agitated to separate the dross accumulated during the melting operation.

The discharge of air contaminants from melting furnaces is generally caused by excessive temperatures and by the melting of metal contaminated with organic material. Fluxing can also create excessive emissions, but fluxes that clean the metal without fuming are available.[3]

The first visible discharge noted from a furnace is from organic material. Before the melt is hot enough to vaporize any zinc, accompanying organic material is either partially oxidized or vaporized, causing smoke or oily mists to be discharged. This portion of the emissions can be controlled either by removing the organic material before the charging to the furnace or by completely burning the effluent in a suitable incinerator or afterburner.

Normally, zinc is sufficiently fluid for pouring at temperatures below 1100°F. At that temperature, its vapor pressure is 15.2 mm. of mercury, low enough that the amount of fumes formed cannot be seen. If the metal is heated above 1100°F, excessive vaporization can occur. Zinc can vaporize and condense as metallic zinc if existing temperatures and atmospheric conditions do not promote oxidation. Finely divided zinc so formed is a definite fire hazard, and fires have occurred in baghouses collecting this material.3/

19.4.1.3 Zinc Vaporization: Retort furnaces are used for operations involving the vaporization of zinc including (1) reclaiming zinc from alloys, (2) refining by distillation, (3) recovering zinc from its oxide, (4) manufacturing zinc oxide, and (5) manufacturing powdered zinc.

Belgian retorts, distillation retorts, and muffle furnaces are used as retort furnaces.3/ Belgian retorts are used to reduce zinc oxide to metallic zinc. Distillation retorts, used for batch distillations, reclaim zinc from alloys, refine zinc, make powdered zinc, and zinc oxide. Muffle furnaces, used for continuous distillation, reclaim zinc from alloys, refine zinc, and make zinc oxide.

The Belgian retort furnace is one of several horizontal retort furnaces that for many years have been the most common device for the reduction of zinc. The horizontal retort process is now being replaced by other methods capable of handling larger volumes of metal per retort and by the electrolytic process for the reduction of zinc ore.3/

Figure 19-3 illustrates a typical Belgian retort. One end is closed and a conical-shaped clay condenser from 18 to 24 in. long is attached to the open end. The retorts are arranged in banks with rows four to seven high and as many retorts in a row as are needed to obtain the desired production. The retorts are generally gas-fired. The air contaminants emitted vary in composition and concentration during the operating cycle. During charging operation very low concentrations are emitted. The feed is moist, and, therefore, not dusty. As the retorts are heated, steam is emitted. After zinc begins to form, both carbon monoxide and zinc vapors are discharged. These emissions burn to form gaseous carbon dioxide and solid zinc oxide. During the heating cycle, zinc is poured from the condensers about three times at 6- to 7-hr. intervals. The amount of zinc vapors discharged increases during the tapping operation. Before the spent charge is removed from the retorts, the temperature of the retorts is lowered, but zinc fumes and dust from the spent charge are discharged to the atmosphere.3/ In addition, the retorts sometimes break and the zinc charge is emitted to the atmosphere in the combustion gases.

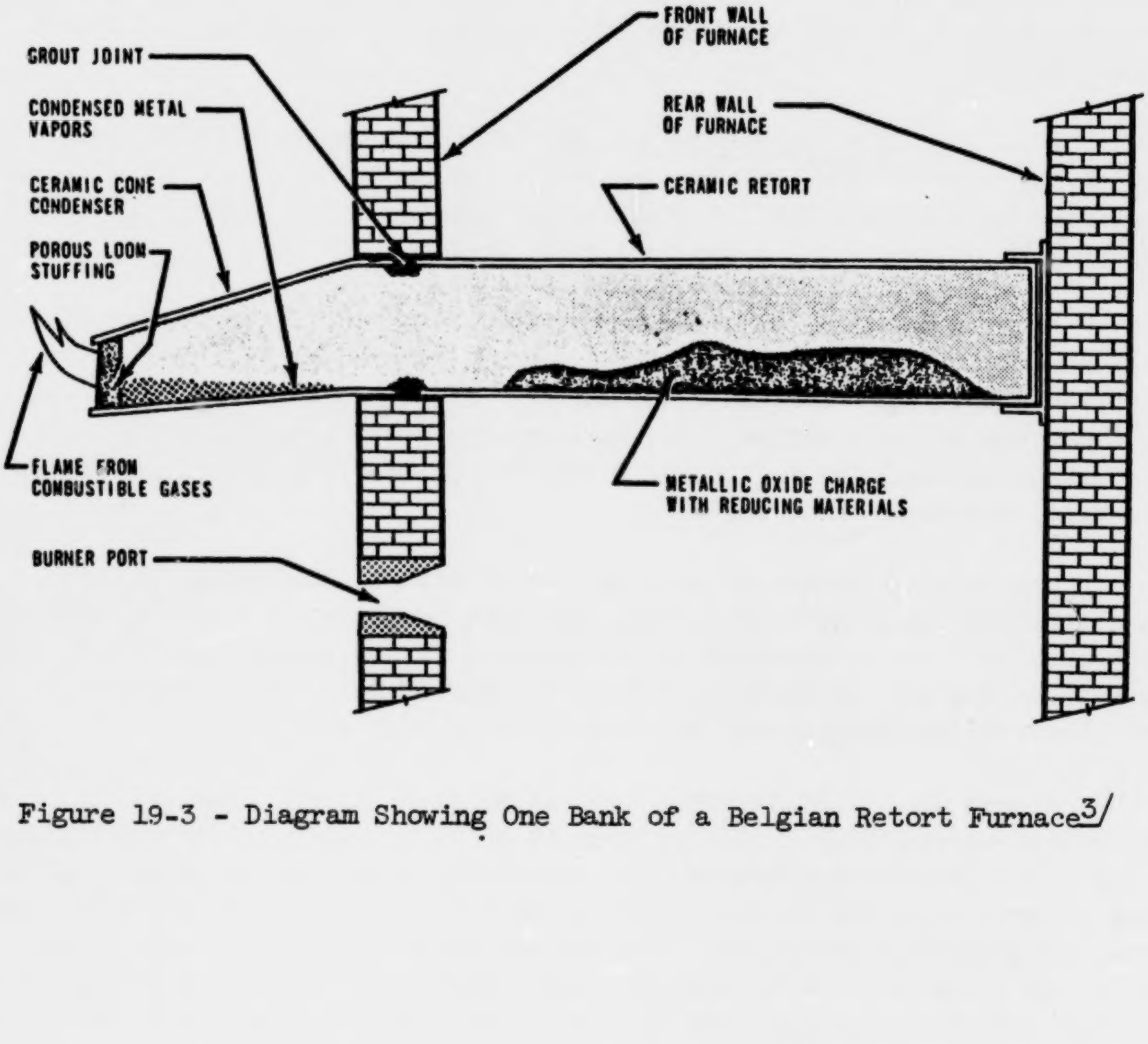

Figure 19-3 - Diagram Showing One Bank of a Belgian Retort Furnace[3]

The distillation retort furnace (shown in Figure 19-4) consists of a pear-shaped, graphite retort, which may be 5 ft. long by 2 ft. in diameter at the open end and 3 ft. in diameter at its widest cross-section. Normally, the retort is encased in a brick furnace with only the open end protruding and it is heated externally with gas- or oil-fired burners. The retorts are charged with molten, impure zinc through the open end, and a condenser is attached to the opening to receive and condense the zinc vapors. After the distillation has been completed, the condenser is moved away, the residue is removed from the retort, and a new batch is started.

During the 24-hr. cycle of the distillation retorts, zinc vapors escape from the retort (1) when the residue from the preceding batch is removed from the retort and a new batch is charged and (2) when the second charge is added to the retort. As the zinc vapors mix with air, they oxidize and form a dense cloud of zinc-oxide fumes. Air contaminants are discharged for about 1 hr. each time the charging hole is open. When the zinc is actually being distilled, no fumes escape from the retort; however, a small amount of zinc oxide escapes from the speise hole in the condenser. Although the emission rate is low, air contaminants are discharged for about 20 hr. per day.

Muffle furnaces (similar to that shown in Figure 19-5) are continuously fed retort furnaces. They generally have a much greater vaporizing capacity than either Belgian retorts or bottle retorts, and they are operated continuously for several days at a time. Heat for vaporization is supplied by gas- or oil-fired burners by conduction and radiation through a silicon carbide arch that separates the zinc vapors and the products of combustion. Molten zinc from either a melting pot or sweat furnace is charged through a feed well that also acts as an air lock. The zinc vapors are conducted to a condenser where purified liquid zinc is collected, or the condenser is bypassed and the vapors are discharged through an orifice into a stream of air where zinc oxide is formed.

Any discharge of zinc vapor from the condenser forms zinc oxide of product purity; therefore, the condenser vents into the intake hood of a product-collecting exhaust system. Since some zinc oxide is always produced, even when the condenser is set to produce a maximum of liquid zinc, the product-collecting exhaust system is always in operation to prevent air contaminants from escaping from the condenser to the atmosphere.[3]

19.4.1.4 Summary of Emission Rates: Table 19-1 summarizes emission-rate data for the various sources in secondary zinc processing. Zinc sweating furnaces account for about 60% of the total quantity of particulates emitted in secondary zinc production.

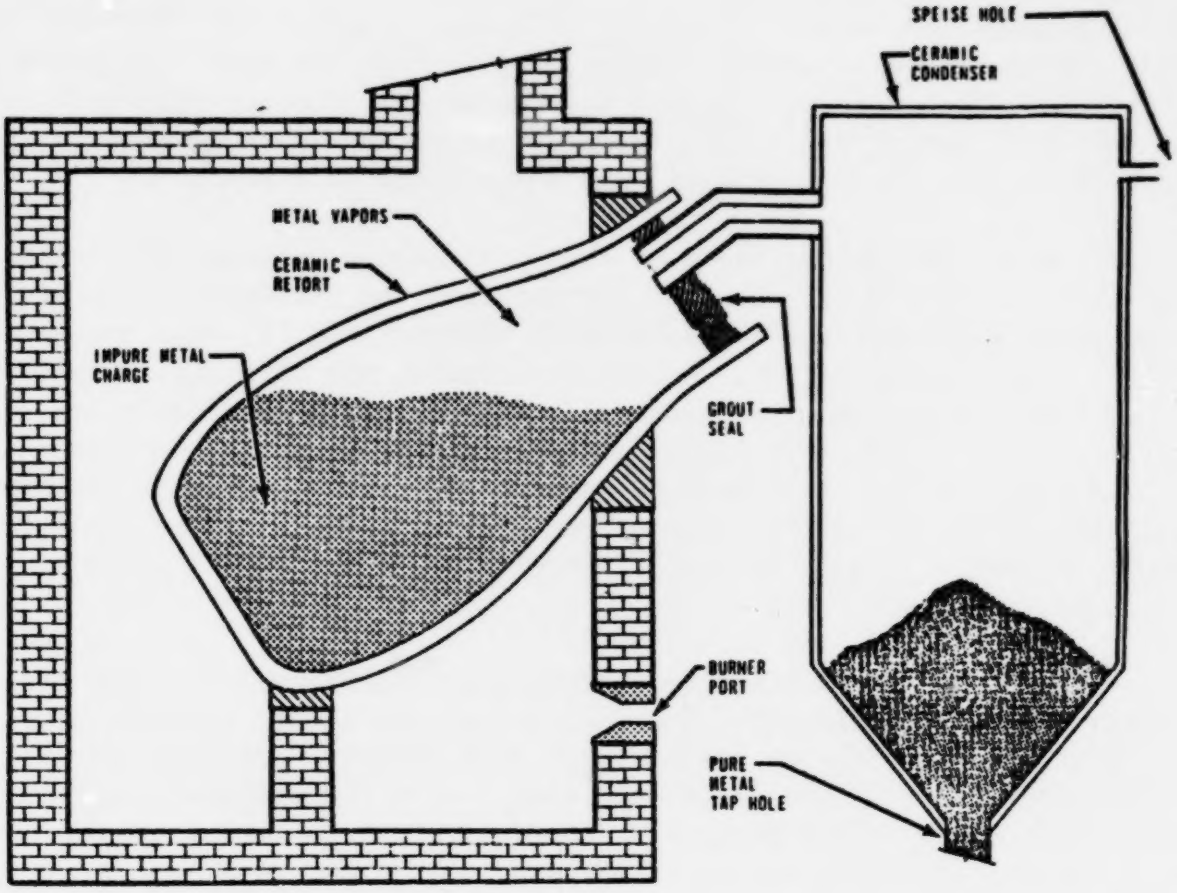

Figure 19-4 - Diagram of a Distillation-Type Retort Furnace[3]

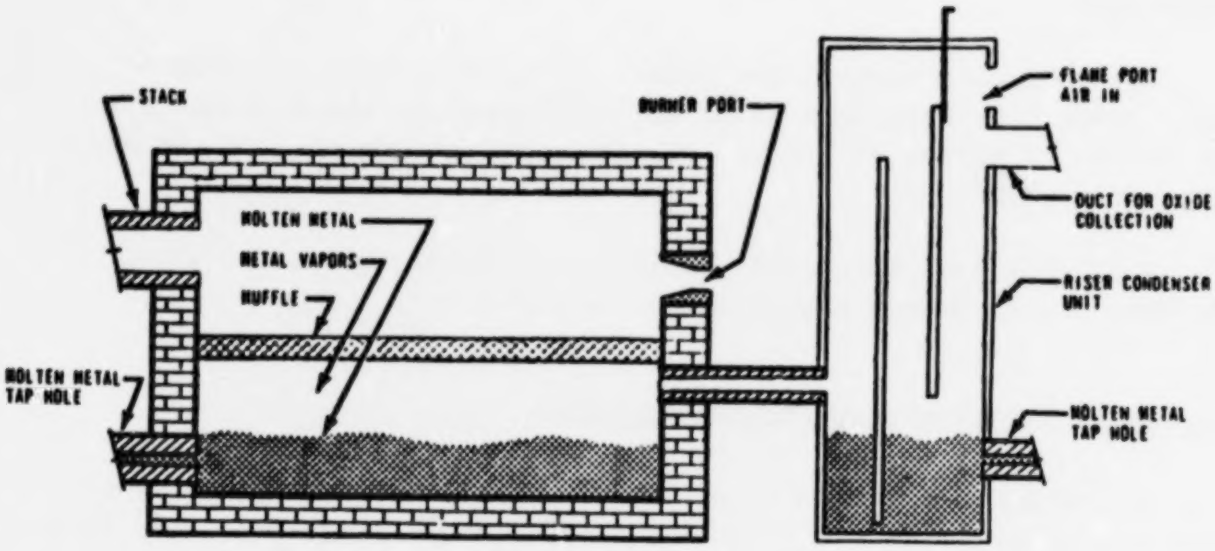

Figure 19-5 - Diagram of a Muffle Furnace and Condenser

19.4.2 Effluent Characteristics

The chemical and physical properties of effluents from secondary zinc production are summarized in Table 19-2. Metallic fumes emitted from the furnaces are submicron in size, and range from 0.03 to 1 μ (unagglomerated material).

19.4.3 Control Practices and Equipment

An afterburner should be provided to incinerate the combustible matter discharged from a low-temperature sweating furnace. A baghouse should be used with the afterburner to capture the dust and fumes. Table 19-11 shows test results for a zinc die-cast sweating operation controlled by a baghouse.[3/]

Air pollution control for retort furnaces is achieved with a baghouse. Glass bags have been found adequate when gas temperatures exceed the limits of cotton or orlon. Filtering velocities of 3 ft/min are generally employed.[8/]

Available data on control equipment costs are presented along with the data for secondary copper in Section 19.2.3.2.

19.5 SECONDARY ALUMINUM SMELTING AND REFINING

Secondary aluminum smelting is essentially the process of remelting aluminum, but encompasses the following additional practices: (1) fluxing, (2) alloying, (3) degassing, and (4) demagging.

Aluminum for secondary smelting comes from three main sources:

1. Aluminum pigs. These may be primary metal but may also be secondary aluminum produced by a large secondary smelter to meet standard alloy specifications.

2. Foundry returns. These include gates, risers, runners, sprues, and rejected castings. In foundries producing sand-mold casting, foundry returns may amount to 40 to 60% of the metal poured.

3. Scrap. This category includes aluminum contaminated with oil, grease, paint, rubber, plastics, and other metals such as iron, magnesium, zinc, and brass.

The melting of clean aluminum pigs and foundry returns without the use of fluxes does not result in the discharge of significant quantities of air contaminants. The melting of aluminum scrap, however, frequently requires air pollution control equipment to prevent the discharge of excessive air contaminants.

TABLE 19-11

DUST AND FUME EMISSIONS FROM AN ALUMINUM- AND A ZINC-SWEATING FURNACE CONTROLLED BY A BAGHOUSE[3]

Test Number	1	2
Furnace data		
Type of furnace	Reverberatory	Reverberatory
Size of furnace	5 ft. 9 in. wide x 6 ft. 4 in. long x 4 ft. high	5 ft. 9 in. wide x 6 ft. 4 in. long x 4 ft. high
Process weight, lb/hr	760	2,080
Material sweated	Aluminum skims	Zinc castings
Baghouse data		
Type of baghouse	Sectioned tubular	Sectioned tubular
Filter material	Orlon	Orlon
Filter area, sq. ft.	5,184	5,184
Filter velocity, ft/min	1.9	1.85
Precleaner	None	None
Dust and fume data		
Gas flow rate, scfm		
Baghouse inlet	8,620	7,680
Baghouse outlet	9,580	7,420
Average gas temperature, °F		
Baghouse inlet	137	190
Baghouse outlet	104	173
Concentration, grains/scf		
Baghouse inlet	0.124	0.205
Baghouse outlet	0.0138	0.0078
Dust and fume emission, lb/hr		
Baghouse inlet	9.16	13.5
Baghouse outlet	1.13[a]	0.5
Control efficiency, %	87.7[a]	96.3

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[a] Visible emissions released from the baghouse indicated that a bag had broken during the latter part of the test.

Crucible and reverberatory furnaces are commonly used for melting aluminum. Both gas- and oil-fired units are common. Electric-induction furnaces are becoming common. Most electric furnaces are relatively small.[3]

19.5.1 Emission Sources and Rates from Secondary Aluminum Smelting

All the pyrometallurgical processes associated with aluminum smelting create air pollutants to some degree. Individual emission sources in the various operations comprising the production cycle for secondary aluminum are discussed in more detail in the following sections.

19.5.1.1 Scrap Processing: Open-flame, reverberatory-type furnaces are used by secondary smelters to produce aluminum pigs for remelting. These furnaces are constructed with the hearths sloping downward toward the rear of the furnace. All types of scrap aluminum are charged into one of these furnaces, which operate at temperatures of 1250° to 1400°F. In this temperature range, the aluminum melts, trickles down the hearth, and flows from the furnace into a mold. The higher melting materials such as iron, brass, and dross oxidation products formed during melting remain within the furnace. This residual material is periodically raked from the furnace hearth. Some large secondary aluminum smelters separate the aluminum suspended in the dross by processing the hot dross immediately after its removal from the metal in the refining furnace. The aluminum globules suspended in the dross can also be separated and reclaimed by a cold, dry-milling process. This process is used primarily to process drosses having a low aluminum content.

In theory, an aluminum-sweating furnace can be operated with minor emissions of air contaminants if clean, carefully hand-picked metal free of organic material is processed. In practice, this selective operation does not occur and excessive emissions periodically result from uncontrolled furnaces. Stray magnesium pieces scattered throughout the aluminum scrap are not readily identified, and charging a small amount of magnesium into a sweating furnace causes large quantities of fumes to be emitted. Emissions also result from the other materials charged, such as skims, drosses, scrap aluminum sheet, pots and pans, aircraft engines, and wrecked airplanes.

Smoke is caused by the incomplete combustion of the organic constituents of rubber, oil and grease, plastics, paint, cardboard, and paper. The sweating of dross and skims is responsible for the high rates of emission of dust and fumes. Residual aluminum chloride flux in the dross is especially troublesome because it sublimes at 352°F and is very hygroscopic. In addition, it hydrolyzes and forms very corrosive hydrogen chloride.

In the dry-milling process, dust is generated at the crusher, in the mill, at the shaker screens, and at points of transfer. These locations must be hooded to prevent the escape of fine dust to the atmosphere.

When aluminum is reclaimed by the hot dross process, some fumes are emitted from the flux action; however, the main air pollution problem is the collection of the mechanically generated dust created by the rotation of the dross barrel.

19.5.1.2 Aluminum Melting: For melting small quantities of aluminum, up to 1,000 lb., crucible or pot-type furnaces are used extensively. Almost all crucibles are made of silicon carbide or similar refractory material. Small crucibles are lifted out of the furnace and used as ladles to pour into molds. The larger crucibles are usually used with tilting-type furnaces. For die-casting, molten metal is ladled out with a small hand ladle, or it can be fed automatically to the die-casting machine.

The reverberatory furnace is commonly used for medium- and large-capacity heats. Small reverberatory furnaces of up to approximately 3,000 lb. capacity may be of the tilting type. Sometimes a double-hearth construction is employed in furnaces of 1,000 to 3,000 lb. holding.

Small crucible furnaces are usually charged by hand with pigs and foundry returns. Many reverberatory furnaces are also charged with the same type of materials, but mechanical means are used because of the larger quantity of materials involved.

Frequently, a large part of the material charged to a reverberatory furnace is low-grade scrap and chips. Paint, dirt, oil, grease, and other contaminants from this scrap cause large quantities of smoke and fumes to be discharged. Even if the scrap is clean, large surface-to-volume ratios require the use of more fluxes, which can cause serious air pollution problems.

The extent of visible emissions discharged from degassing aluminum with chlorine gas depends on metal temperature, chlorine flow rate, and magnesium content of the alloy. Other factors affecting the emissions to a lesser degree are the depth at which the chlorine is released and the thickness and composition of the dross on the metal surface.3/

When chlorine is used for demagging, it is added so rapidly that large quantities of both aluminum chloride and magnesium chloride are formed, the molten bath is vigorously agitated, and not all of the chlorine reacts with the metals. As a result, a large quantity of aluminum chloride is discharged along with the chlorine gas and some entrained magnesium chloride. The aluminum chloride is extremely hygroscopic and absorbs moisture from the air, with which it reacts to form hydrogen chloride. These air contaminants are toxic, corrosive, and irritating.

19.5.1.3 Summary of Emission Rates: Table 19-1 summarizes emission-rate data for the various sources in secondary aluminum processing. Chlorine fluxing operations for degassing and demagging steps account for 51,000 tons/year out of a total of approximately 58,000 tons/year of emitted particulates.

19.5.2 Characteristics of Effluents

The chemical and physical properties of effluents from secondary aluminum production are summarized in Table 19-2. Emitted particulates are less than 2 μ in size. The particulates may be toxic because of the fluorides and chlorides that are emitted.

19.5.3 Control Practices and Equipment

In aluminum-sweating operations, raking the residual metal and dross from the furnace is a critical operation from an air pollution standpoint, and hoods should be installed to capture emissions at these locations.

An afterburner followed by a baghouse is recommended as control equipment for an aluminum-sweating furnace. Baghouse filtering velocities should not exceed 3 ft/min. The afterburner must be so designed that the carbonaceous material is intimately mixed with the exhaust air and held at 1200° to 1400°F for a retention time of about 0.3 sec. Secondary air may have to be admitted to the afterburner to ensure complete combustion.

The hot gases must be cooled before entering a baghouse, and radiant cooling or dilution with cold air is recommended in preference to evaporative cooling with water. If hot furnace gases are cooled with water, the aluminum chloride hydrolyzes, producing hydrochloric acid that attacks the ductwork and bags. Even the condensation from night air during shutdown provides sufficient moisture to corrode the equipment in the presence of these chemicals. Tables 19-11 and 19-12 show test results on control systems for aluminum-sweating furnaces.[3/]

The wet scrubber is particularly suitable for the aluminum smelter. Spray quenching of the hot furnace gases creates steam which reacts with aluminum chloride gas to form soluble hydrated aluminum oxide and hydrochloric acid; both of these are relatively easy to remove in an appropriately designed and operated scrubber. In order to obtain adequate collection efficiency, the use of high-efficiency wet scrubbers, with a caustic solution as the scrubbing medium, has been found necessary. Table 19-13 shows typical test data on collection efficiency for various wet scrubbers.[8/]

To adequately control emissions from chlorinating aluminum, the wet scrubber may be followed by a baghouse or electrical precipitator. At present the trend in control equipment for aluminum-fluxing emissions appears to be away from electrical precipitators and toward the scrubber-baghouse combination.[8/]

TABLE 19-12

DUST AND FUME EMISSIONS FROM AN ALUMINUM-SWEATING FURNACE CONTROLLED BY AN AFTERBURNER AND BAGHOUSE[3]

Furnace data	
Type of furnace	Reverberatory with integral afterburner
Furnace hearth area	4 ft. 7 in. wide x 8 ft. 10 in. long
Process weight, lb/hr	2,870
Material sweated	Scrap aluminum
Baghouse data	
Type of bags	Tubular
Filter material	Dacron
Filter area, sq. ft.	4,800
Filter velocity, ft/min	2.16
Precleaner	Settling chamber

Dust and fume data	Settling Chamber Inlet	Furnace Charge Door Hood	Baghouse Outlet
Gas flow rate, scfm	1,360	5,580	8,850[a]
Average gas temperature, °F	350	204	150
Concentration, grains/scf	0.505	0.081	0.0077
Dust and fume emission, lb/hr	5.89	3.88	0.58
Particulate control efficiency, %			94.1

Orsat analysis at settling chamber inlet, volume %	
CO_2	6.8
O_2	8.6
CO	0.02
N_2	77.33
H_2O	7.25

Particle size analysis at baghouse outlet, wt. %	
+60 mesh	85.9
-60 mesh	14.1

Particle size analysis of -60 mesh portion, wt. %	
0 to 2 µ	6.9
2 to 5 µ	32.4
5 to 10 µ	30.9
10 to 20 µ	17.7
20 to 40 µ	7.7
< 40 µ	4.4

Combustible carbon in particulate discharge, dry wt. %	
Settling chamber inlet	83.7
Furnace chamber door hood exit	67.3

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[a] Volume is greater at the baghouse exit than at the inlet because of leakage.

TABLE 19-13

SCRUBBER COLLECTION EFFICIENCY FOR EMISSIONS FROM CHLORINATING ALUMINUM[8]

(Scrubber Collection Efficiencies, %)[a]

	Slot Scrubber		Packed-Column Scrubber	
Contaminants	Water	10% Caustic Solution	Water	10% Caustic Solution
HCL	90 to 95	95 to 99	95 to 98	99 to 100
CL_2	30 to 50	50 to 60	75 to 85	90 to 95
Particulates	30 to 50	50 to 60	70 to 80	80 to 90

---

[a] Collection efficiency depends mainly upon scrubbing ratio (gal/1,000 cu.ft.), velocity of gas in scrubber, and contact time and, to a lesser extent, on other aspects of the design. These values are typical efficiencies obtained by actual tests but do not reflect the entire range of results.

More precise controls need to be developed and methods need to be found to adapt the wet scrubber to the peak chlorine "burn-off" cycle when the temperature of the aluminum furnace is raised to volatilize all residual chlorine from the system.[6]

Available data on control equipment costs are presented along with the data for secondary copper in Section 19.2.3.2.

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CHAPTER 20

COAL PREPARATION PLANTS

20.1 INTRODUCTION

An expanding market demand for high-quality fine-mesh coal has necessitated improvement and enlargement of fine-coal preparation facilities. The primary purpose of a preparation plant is to crush the coal, remove impurities, and classify the product into standard sizes. The equipment and processes involved in coal preparation are similar to those used in the beneficiation of most mineral ores. These are generally wet processes which do not, in themselves, cause air pollution problems. However, when the wet product must be dried to prevent freezing due to cold weather or to satisfy customer specifications, significant air pollution problems can occur.

The major air pollution problems associated with coal-preparation procedures are gaseous emissions from ignited coal-refuse disposal areas, dust from refuse and coal-storage piles, and particulate matter from coal dryers and de-dusting operations.1/ The coal-cleaning process, particulate emission sources, particulate emission rates, effluent characteristics, and control practices and equipment are reviewed in the following paragraphs.

20.2 COAL-CLEANING PROCESS

The great increase in mechanization and full seam mining has resulted in substantial increases in the impurity content of the raw coal as well as in a finer size content. As a result, the percentage of coal cleaned by mechanical methods has increased from only 24% of the total production of bituminous and lignite coal in 1942 to 65% in 1965. The amount of refuse discarded during preparation for the same period increased from 13 to 21%. Changes in the equipment used in the cleaning process were as follows:

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MECHANICAL CLEANING BY PROCESS, PERCENT[15]

Process	1942[a]	1965
Jig	47	46
Dense-medium	9	29
Table	2	13
Pneumatic	14	8
Classifier	7	2
Launder	13	1
Flotation	< 1	2

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[a] Unclassified nearly 8%. Data on the amount cleaned by flotation was not collected until 1960 when 1.8 million net tons was so treated. In 1965 this figure increased to 6.9 million tons.

The principal mechanical cleaning processes are discussed in more detail in the following paragraphs.

20.2.1 Hydraulic Separation and Concentration

20.2.1.1 Hydraulic Separation - Jigging: Jigging is a process of particle stratification in which the particle rearrangement results from an alternate expansion and compaction of a bed of particles by a pulsating fluid flow. The particle rearrangement results in layers of particles which are arranged by increasing density from top to bottom of the bed. This response, developed from the many and continuously varying forces acting upon the particles, is a solid-fluid separation more related to particle density and less to particle size than any other "hydraulic type" process. The stratification is usually carried out in a rectangular, open-top container, called a jig, in which the mass of particles (termed a "bed") is supported on a perforated base through which the water flows in alternating directions. Following the particle stratification, the particle bed is physically "cut" at any desired particle density plane thus creating the desired quality products. The jig includes means for continuously introducing the raw coal, for moving the water through the coal bed in a controllable manner as well as for separating and removing the stratified particles from the system as two or more product streams. In coal preparation, this highly versatile unit operation is more preferably applied to a wide size-range of particles with top sizes up to 8 in. than to a closely sized fraction.[15]

Single jig washers have capacities from 5 to > 700 tons/hr of feed coal. The separation results attainable by jigging have favored this unit operation as optimum for creating a clean coal product as required by steam coal specifications. Although the jig is used in preparing coals which are difficult to separate, its limitations to achieve both quality products and high recovery are being recognized in comparison with heavy media-based processes which make sharper separations from feeds having high "near-gravity" contents. Thus the accuracy of the densimetric stratification in the upper portions of the jig bed is less precise. In jigging, as in most mineral-preparation unit operations, high recovery and product quality are interdependent and inverse process characteristics.[15]

20.2.1.2 Hydraulic Concentration: Hydraulic concentrating devices depend on the physical characteristics, size, shape, and density of particles suspended in a liquid medium to effect a concentration of desired quality.

The principal fine-coal washers utilized in the United States today are wet concentrating tables, cyclones, launders, feldspar jigs and hydrotators. Of these the concentrating table is the most popular, especially in the cleaning of bituminous coal. Cyclone types are becoming increasingly important in washing both anthracite and bituminous coal. The launders and feldspar jigs are utilized on a limited scale for cleaning bituminous coal and the hydrotator is used extensively for cleaning anthracite.

Fine-coal hydraulic concentrating devices generally include those devices which clean 3/8 in. top-size coal. This is an arbitrary size which seems most consistent with actual practice, although certainly these devices can effectively clean coarser or finer coal.[15]

20.2.2 Dense Medium Separation

Dense medium separations include those coal-preparation processes which clean raw coal by immersing it in a fluid having a density intermediate between clean coal and reject. As there is a general correlation between ash content and specific gravity, it is possible to achieve the required degree of removal of ash-forming impurities from a raw coal by regulating the specific gravity of the separating fluid.

Dense medium processes offer the following advantages over other coal cleaning processes:

1. Ability to make sharp separations at any specific gravity within the range normally required even in the presence of high percentages of the feed in the range of ± 0.1 specific gravity units.

2. Ability to maintain a separating gravity that can be controlled with ± 0.005 specific gravity units.

3. Ability to handle a wide range of sizes (up to 14 in.).

4. Relatively low capital and operating costs when considered in terms of high capacity and small space requirements.

5. Ability to change specific gravity of separation to meet varying market requirements.

6. Ability to handle fluctuations in feed both in terms of quantity and quality.15/

Commercial application of the dense medium process is a practical extension of the familiar laboratory float-and-sink test, which is used as a standard (100% efficiency) gravimetric separation. Commercial plants do not exactly duplicate laboratory float-and-sink separations for the following reasons: suspensions, rather than true liquids, usually are used as separating media; the introduction of feed and removal of the float and sink introduce disturbances in the separating medium; agitation, or upward currents in the vessel, normally are required to keep the separating medium in suspension; and the practical need for high throughput does not allow sufficient retention time for perfectly separating near-gravity material.

Theoretically, any size particle can be treated by dense medium processes; practically, the sizes treated range from about 0.5 mm. (32 mesh) to about 6 in., although sizes ranging up to 14 in. occasionally are washed. Sizes coarser than about 1/4 in. normally are treated in static dense medium separators, while the size range 0.5 mm. to about 1/4 in. normally is washed in separators employing centrifugal force; for example, the dense medium cyclone washer.15/

20.2.3 Froth Flotation

Flotation is a chemical process that depends on the selective adhesion to air of some solids and the simultaneous adhesion to water of other solids. A separation of coal from coal waste then occurs as finely disseminated air bubbles are passed through a feed coal slurry. Air-adhering particles (usually the coal) are separated from nonadhering particles, floated to the surface of the slurry and then removed as a concentrate. This process involves the use of suitable reagents to establish a hydrophobic or air-adhering surface on the solids to be floated, and to render the other solids hydrophilic. As shown in Section 20.2, the flotation process accounted for about 2% of the coal cleaned by mechanical methods in 1965.15/

20.2.4 Dry Cleaning and Concentration

The particular field of application of machines utilizing air currents as the primary separating medium is in the cleaning of the fine sizes of bituminous coal. Approximately 25,400,000 tons of bituminous coal were cleaned by air machines during 1965. No application has been found for cleaning anthracite.

Seven successful pneumatic coal-cleaning machines have been developed and introduced to the American coal-mining industry:

1. Peale Davis: "Pneumo-Gravity" machine
2. Arms "Concentrator," oscillating table
3. Heyl and Patterson oscillating table
4. "Stump Air-Flow," pulsating air jig
5. "Super Airflow," pulsating air jig
6. Ridge air jig
7. Phillip air jig

While not all coals can be beneficiated by air washing, the air washing of coals that are easy to clean can be readily proved advantageous. Of all the preparation methods, pneumatic cleaning is the most acceptable from the standpoint of delivered Btu cost. This is based on the premise that a percent of moisture is just as detrimental as a percent of ash.

Historically most air-cleaning devices used a vertical upward current of air through the bed of material. They differed by the method of imparting mobility to the bed and the method of removing the refuse. In general terms, the air machines were divided into three types:

1. Pneumatic jigs where the air current was pulsated.

2. Pneumatic tables where the refuse was diverted from the direction of flow of the clean coal by a system of riffles fixed to the deck.

3. Pneumatic launders where the products flowed in the same direction, and the clean coal was skimmed off the top of the bed and/or the refuse was extracted from the bottom in successive stages.

In recent years, however, the latter two types of units have declined in popularity. In fact, a survey of the industry revealed that all of the air-cleaning machines in use in 1966 depended on pulsating air as the medium of concentration.

Dry concentration of coal has come a long way in recent years. Today, there are numerous examples of successful plants treating 3/8 in. by 0 and 1/4 in. by 0 coal and coal as large as 2-1/2 in. in capacities up to 350 tons/hr. Although the rate of installations has tapered off, there were over 200 full-size units of airflow equipment in operation in 1965 processing over 20 million tons of coal annually.[15]

These are indications that the downward trend in new air-cleaning installations may be reversed in the not too distant future. Governmental regulations are placing greater and greater emphasis on control of both stream and air pollution originating from preparation plants. Pneumatic cleaning has the inherent advantage in this regard in that it does not contribute to stream pollution at all, as may water cleaning techniques. Similarly, although air cleaning plants admittedly can be dusty, the majority of the dust is confined within the plant and particulate emission to the atmosphere away from the plant is minor if cloth filters are used. Also, dry concentration obviously will not cause thermal or chemical pollution of the air. These considerations may therefore weigh heavily in favor of air cleaning as regulations inevitably become more stringent through increased governmental action.

A second factor which may contribute heavily to increased use of dry cleaning techniques is the fact that recent evidence indicates that less extensive cleaning of some coals may tend to minimize corrosion of fire-side boiler tubes in power plants. With some coals, extensive cleaning to minimize the ash content in the washed coal contributes to boiler tube corrosion by removing ash constituents such as alkaline earth materials (e.g., CaO and MgO) which are corrosion inhibitors while removing lesser amounts of corrosion-promoting constituents such as alkalies (e.g., Na_2O and K_2O). Thus, by cleaning at lower specific gravities to reduce ash, the ratio of corrosion promoters to corrosion inhibitors in the ash increases when preparing some coals for market. Extensive cleaning and the resultant lower yield may therefore, in some instances, contribute to corrosion rather than reducing it as is desired. In fact, it has been shown that, some run-of-mine coals are more desirable from both a corrosion and a yield standpoint than they are after cleaning.

In addition to these factors, several other major advantages are inherent to dry concentration techniques. The largest advantage is the simple fact that dry concentration requires the lowest initial capital investment and has the lowest maintenance costs of all currently used methods of upgrading fine coal. There is also continuing realization on the part of operators and consumers of the necessity for providing a dry coal for freeze-free shipments. Air-washed coal is also more amenable to oil treatment for dust control and it flows freely and does not arch in bins and hoppers. In transit, dry-cleaned coal will shed rain and arrive with only the surface of the car wetted whereas wet-washed, thermally dried coal may act as a sponge and soak up water. The rigid enforcement of stream pollution laws gives a permament advantage to dry concentration as discussed above. Admittedly, wet fine coal cannot be cleaned with air and Federal regulations cause more and more coal to be wetted at the face. However, it is more economical to pre-dry the coal for dry concentration than to dry the washed coal after it is recovered from the water. A further factor influencing the choice of pneumatic equipment is the lack of sufficient water in arid regions, localities of high altitude or cold climates.[15]

20.2.5 Thermal Drying

The continuing increase in the percentage of minus 1/4 in. coal produced as a result of the increased use of mechanical mining methods has, over the years, tended to shift considerable portions of the work of producing salable coal to the fine-coal cleaning section of the preparation plant. Because a given weight of fine coal will contain substantially greater surface area than an equivalent weight of coarse coal, it follows that, when subjected to wet-cleaning processes, the fines will absorb and retain considerable more moisture than coarser fractions. Increased moisture pickup in the finer size complicates fine coal cleaning since beneficiation may not be limited to the removal of ash and sulfur but often must be expanded to include the additional step of thermal drying to remove excessive moisture. Thus, water which provides the medium for cleaning fine coal is in itself detrimental and, like ash and sulfur, reduces coal quality.

Removal of surface moisture by drying is done for one or more of the following reasons: (1) to avoid freezing difficulties and to facilitate handling during shipment, storage and transfer to the points of use; (2) to maintain high pulverizer capacity; (3) to reduce heat loss due to evaporation of surface moisture from the coal in the burning process, thus increasing heating efficiency; (4) to improve the quality of coal used for special purposes, such as in the production of coke, briquettes, and chemicals; (5) to decrease transportation costs; and (6) to facilitate dry coal cleaning processes.[15]

Coal dryers can be grouped into six basic types. The six basic dryer types are: (1) fluidized bed; (2) suspension or flash; (3) multi-louvre; (4) vertical tray and cascade; (5) continuous carrier; and (6) drum or rotary type.[15] Figures 20-1 to 20-4 illustrate various types of thermal dryers.

Recent coal industry trends in the application of the preceding types of drying facilities are indicated in Table 20-1. The expanding general application of coal drying (from 31.5 to 58.7 million tons between 1958 and 1964) and the expanding specific application of fluidized-bed coal drying (from 10.6 to 38.3% of all coal dryers between 1958 and 1964) are noteworthy.

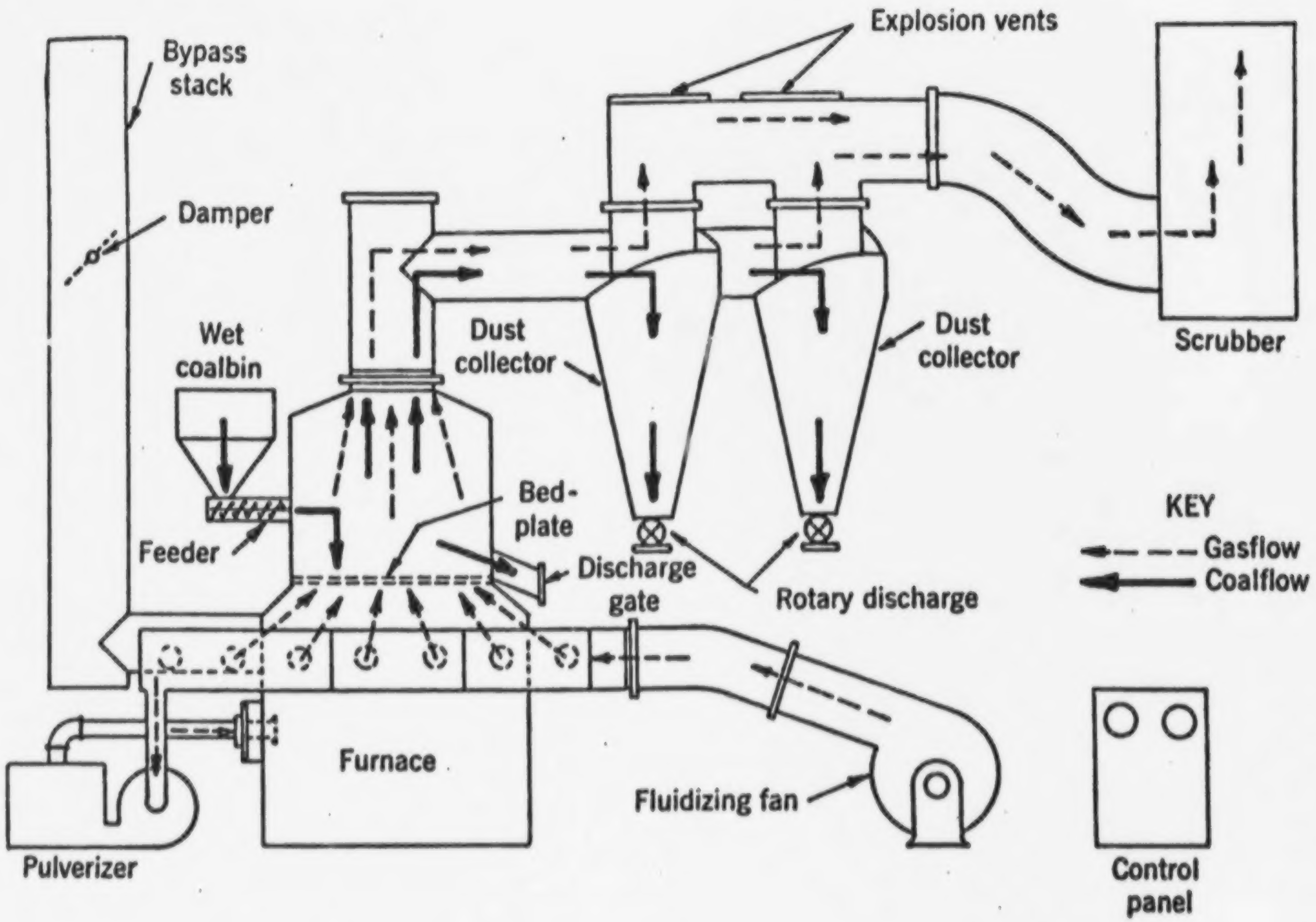

Figure 20-1 - Pressure-Type Fluidized-Bed Thermal Coal Dryer, Showing Component Parts and Flow of Coal and Drying Gases[3]

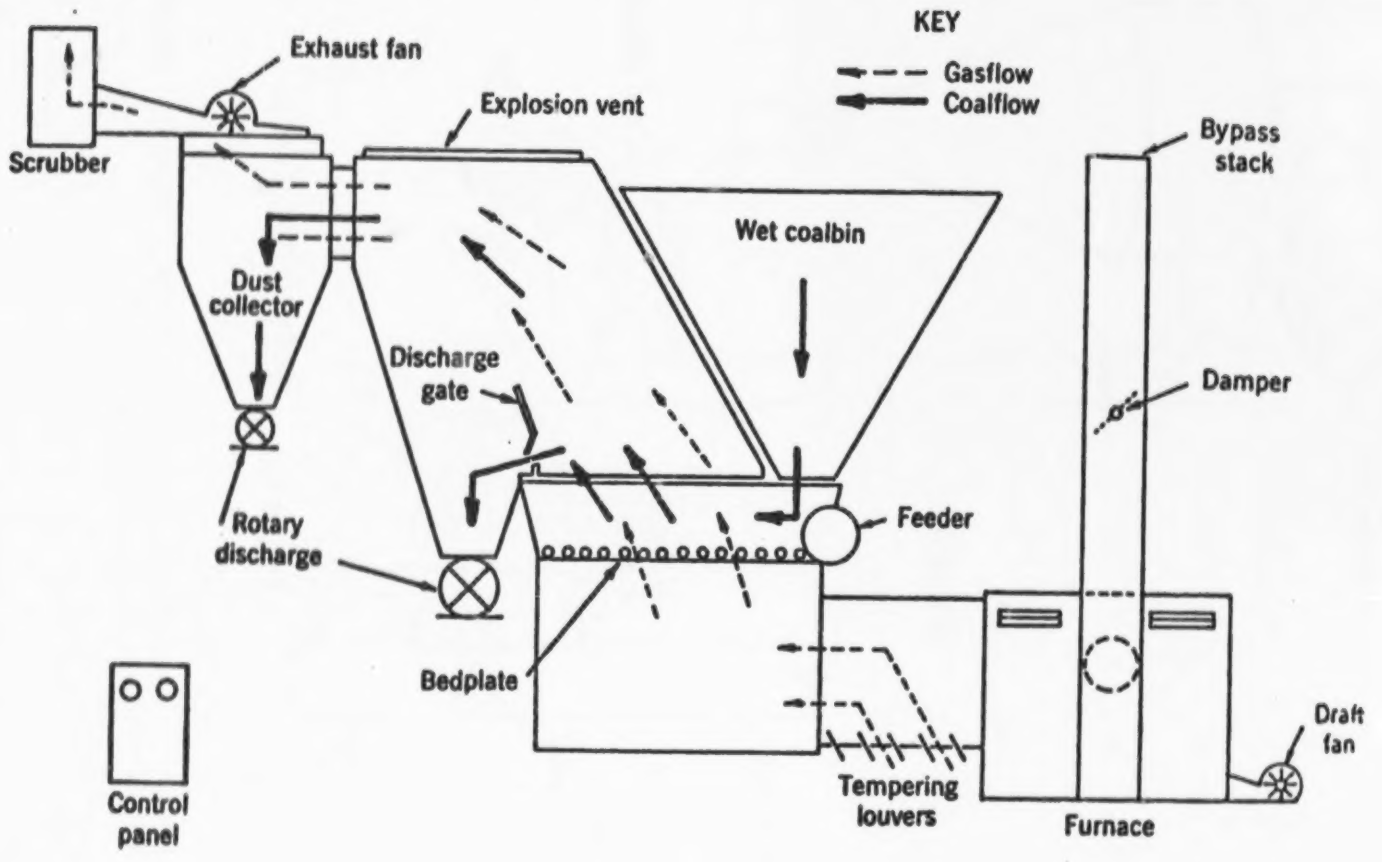

Figure 20-2 - Exhausting-Type Fluidized-Bed Thermal Coal Dryer, Showing Component Parts and Flow of Coal and Drying Gases3/

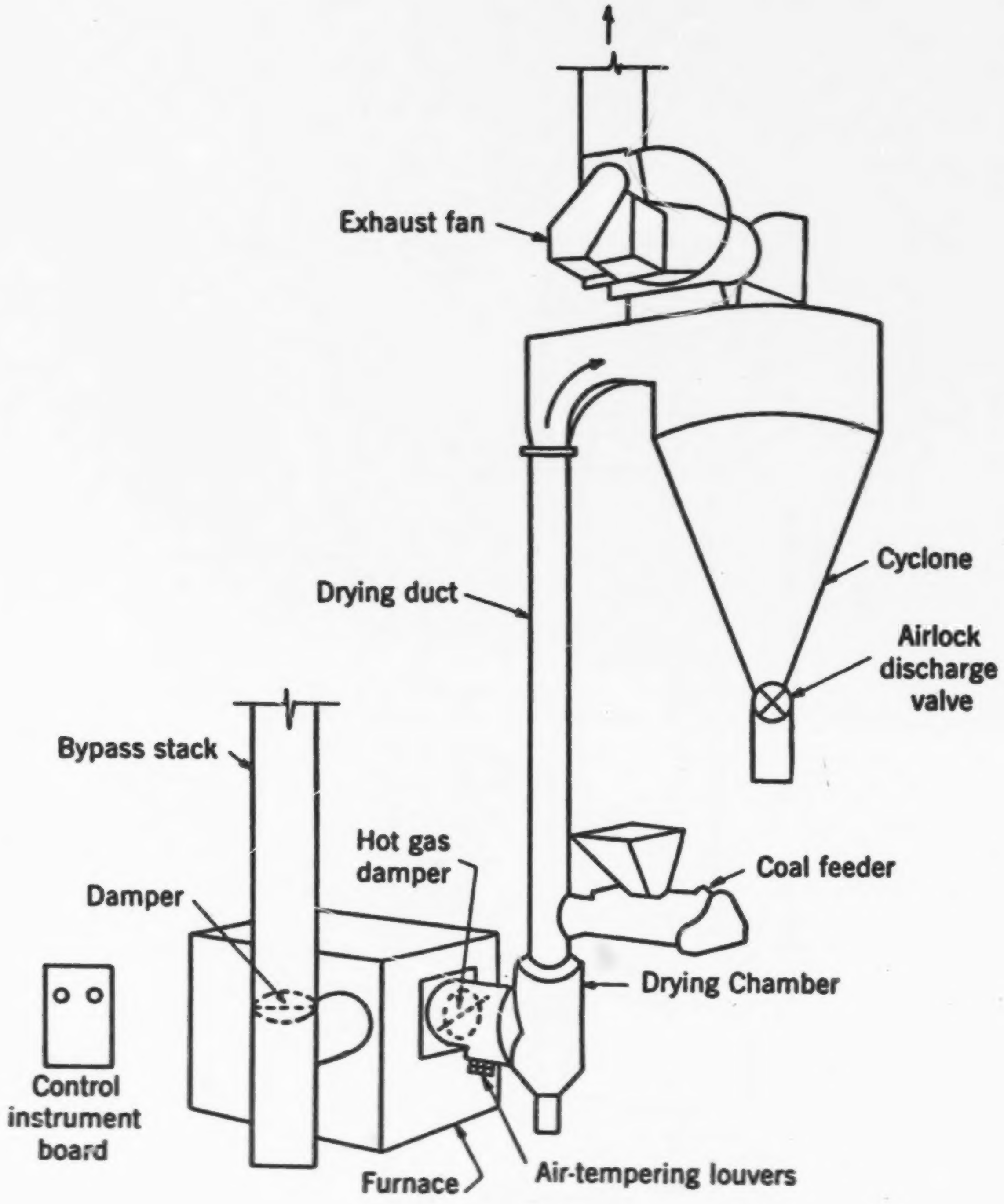

Figure 20-3 - Schematic Drawing Showing Component Parts of Flash-Drying Unit[4]

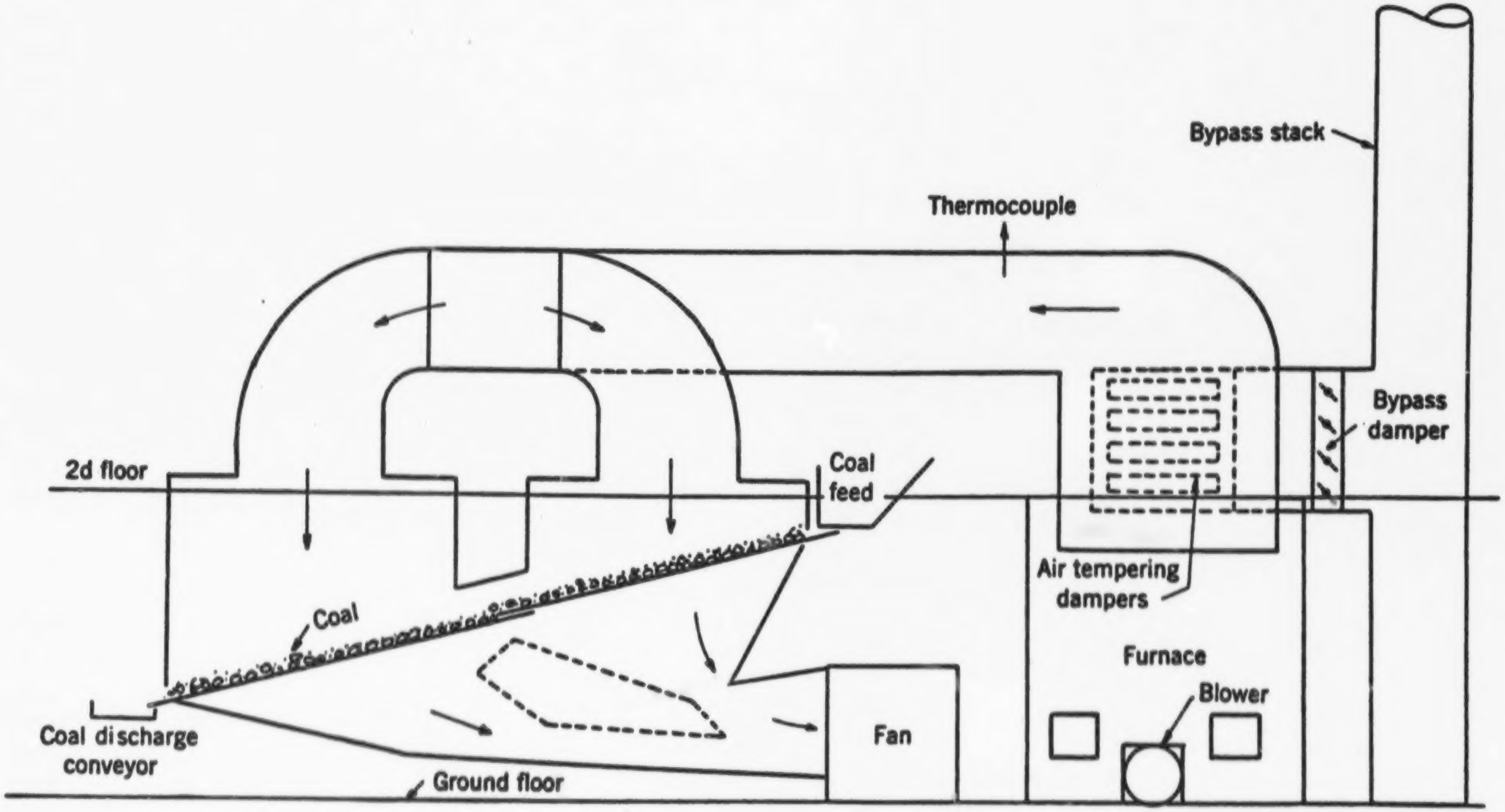

Figure 20-4 - Schematic Sketch of Screen-Type, Thermal Coal-Drying Unit[4]

TABLE 20-1

THERMALLY DRIED COAL BY TYPES OF DRYING EQUIPMENT, 1958-1964[15/]

Year	Rotary	Continuous Carrier	Vertical Tray and Cascade	Multi-Louvre	Suspension or Flash	Fluidized Bed	Total
				Number of Plants			
1958	6	64	58	50	44	6	228
1959	9	66	57	55	48	12	247
1960	11	63	58	57	47	16	252
1961	11	66	64	56	40	23	260
1962	11	60	59	49	58	29	266
1963	11	57	54	44	49	38	253
1964	9	56	50	42	49	49	255
				Net Tons Dried			
1958	405,057	7,774,090	5,775,347	9,416,368	4,834,324	3,336,929	31,542,125
1959	717,948	8,381,332	5,682,861	9,734,894	6,625,409	4,622,292	35,764,736
1960	771,014	8,099,827	5,023,497	11,469,532	6,479,501	6,025,026	37,868,397
1961	1,007,814	8,989,457	5,574,594	10,611,069	5,681,477	7,768,609	39,633,040
1962	1,998,254	8,931,633	5,856,812	9,631,349	8,105,551	12,432,991	46,956,590
1963	2,549,294	9,499,674	6,048,360	9,469,847	8,131,081	14,857,074	50,555,330
1964	1,959,496	9,658,965	5,507,522	9,943,032	9,154,519	22,478,004	58,701,538
				Percent of Total			
1958	1.3	24.7	18.3	29.8	15.3	10.6	100.0
1959	2.0	23.5	15.9	27.2	18.5	12.9	100.0
1960	2.0	21.4	13.3	30.3	17.1	15.9	100.0
1961	2.5	22.7	14.1	26.8	14.3	19.6	100.0
1962	4.2	19.0	12.5	20.5	17.3	26.5	100.0
1963	5.0	18.8	12.0	18.7	16.1	29.4	100.0
1964	3.3	16.5	9.4	16.9	15.6	38.3	100.0

20.3 EMISSION RATES FROM COAL PREPARATION PLANTS

Because coal is relatively friable, the mining and subsequent handling operations break part of the coal into dust that can be readily carried by currents of air. In a coal preparation plant mechanical handling operations such as unloading, transferring from one belt to another, screening, cleaning, and crushing in a dry state result in the generation and release of varying amounts of additional dust. The dust problem, of course, is much less serious in plants employing entirely wet processing. In addition to dust from handling operations, thermal drying of the fine coal product frequently presents another dust collection problem.

All industrial coal dryers now in use are the continuous direct contact type which employ convection as the major principle of heat transfer. Thus, hot gases and wet coal are brought into intimate contact with each other on a continuous gas flow-coal feed basis. To achieve drying, hot gases are generated in a combustion chamber and brought into contact with wet coal by a fan or blower. The size consistency of the coal being dried and the velocity of the gases through the bed are major factors in determining the air pollution potential of the plant. Emissions include products of combustion and entrained coal fines.

The calculation of emissions from thermal dryers based on the use of an emission factor is not accurate since the emissions from each type of dryer vary over a wide range depending on operating methods. The flash dryer carries all of the product into a product separation cyclone, while the fluid-bed type may carry over from 5% to 50% of the product into the cyclone collection system. For these reasons, the emissions are best calculated on the basis of average outlet grain loadings from control equipment, as was done in a recent internal NAPCA study.[5]

The NAPCA study included a survey of thermal dryers operated at eight of the largest coal companies. The survey covered about 60% of the total coal dried yearly in the U. S. It determined a total air flow from these dryers of 1.16 x 10^{12} scf/year.[3]

This survey also indicated that 50% of the dryers were equipped with cyclones, while the remaining 50% were equipped with cyclones plus some type of wet scrubber. Total emissions were then calculated to be in the order of 300,000 tons/year assuming an outlet grain loading of 4.0 grains/scf from cyclones, 0.15 grain/scf from low-energy scrubbers, and 0.04 grain/scf from high-energy scrubbers.

The assumed grain loadings have been found to correspond with data in the literature and data from the West Virginia Air Pollution Control Commission. However, the fact that 50% of the dryers are equipped with only cyclones seemed low in view of a 1967 West Virginia Air Pollution Control Commission survey which indicated that less than 15% of the dryers in that state had cyclones only.[6]

Further analysis of the NAPCA survey showed that 50% of the dryers did have cyclones only, but these represented only 13.8% of the total air flow. On this basis, the emissions are calculated in the following manner:

$$(1.16 \times 10^{12} \text{ scf/year})(13.8\%)\left(\frac{4 \text{ grains}}{\text{scf}}\right)\left(\frac{1 \text{ ton}}{14 \times 10^{6} \text{ grains}}\right) = 45{,}700 \text{ tons/year}$$

$$(1.16 \times 10^{12} \text{ scf/year})(86.2\%)\left(\frac{0.15 \text{ grains}}{\text{scf}}\right)\left(\frac{1 \text{ ton}}{14 \times 10^{6} \text{ grains}}\right) = 10{,}700 \text{ tons/year}$$

Total 56,400 tons/year

If this represents about 60% of the coal dried, the total annual particulate emissions from thermal dryers are 94,000 tons/year.

A second method of calculating emissions, for comparison purposes, can be done on the basis of emission factors for the dryers. Data in Reference 17 show that the emission factor for the outlet of the dryer cyclone is 12 lb/ton for flash dryers and 13 lb/ton for fluid bed dryers. The emission factor for the other types of dryers is probably somewhat lower since their mode of operation should not carry out as much dust to the cyclone. This includes the rotary, continuous carrier, cascade, and multi-louvre dryers.[15] However, it might be assumed that the average overall emission factor is 12 lb/ton, although this may be somewhat high. The calculation of the emissions also involves the question of what percent of the coal is dried in units that are equipped with wet scrubbers. The two calculations given below show the quantities emitted on the basis of two different assumptions. The efficiency of the wet scrubbers has been estimated at 95% for both cases.

a. It is assumed that 50% of the coal is dried in units equipped with wet scrubbers. This is similar to the NAPCA study which assumed that 50% of the total air flow for all dryers is cleaned in wet scrubbers. The NAPCA survey actually showed that 50% of the number of dryers were equipped with wet scrubbers and it was presumed that this also represents 50% of the total air flow. The emissions for this assumption are calculated as:

$$(73{,}000{,}000 \text{ tons/year})\left(\frac{2{,}000 \text{ lb/ton}}{12 \text{ lb/ton}}\right)(1 - (0.50)(0.95)) = 230{,}000 \text{ tons/year}$$

b. It is assumed that 85% of the coal is dried in units equipped with wet scrubbers. This assumption is based on our analysis of the data in the NAPCA survey and is supported by information from the West Virginia Air Pollution Control Commission. The emissions for this assumption are calculated as:

$$(73{,}000{,}000 \text{ tons/year})\left(\frac{12 \text{ lb/ton}}{2{,}000 \text{ lb/ton}}\right)(1 - (0.85)(0.95)) = 83{,}000 \text{ tons/year}$$

These results support the previously discussed emission calculations but do not resolve the question of the extent to which thermal dryers are equipped with wet scrubbers. Based on the present information and calculations described in this section it is felt that the emission quantity of 94,000 tons/year is the more accurate figure.

Insufficient data were available to calculate particulate emission rates from the secondary sources. Also, data could not be found on particulate emissions from burning coal refuse banks. Reference 7 reports an emission level of 400,000 tons/year of particulate from coal refuse. This figure was calculated assuming that the emission factor for refuse piles corresponds to that for open burning. This is a questionable assumption, and the number of 400,000 tons/year is considered a gross estimate.

20.4 CHARACTERISTICS OF COAL-PREPARATION-PLANT EMISSIONS

The chemical and physical properties of coal-preparation-plant emissions are summarized in Table 20-2. Particulates generated during thermal drying present fire and explosion hazards both within drying chambers and cyclones, fans, and duct work beyond the drying chamber.

20.5 CONTROL PRACTICES AND EQUIPMENT FOR COAL-PREPARATION PLANTS

20.5.1 Thermal Drying Plant

In most thermal drying plants a system of control units is utilized with dry collectors serving as primary dust separators and wet collectors serving as secondary dust separators.[8/]

TABLE 20-2

EFFLUENT CHARACTERISTICS - COAL PREPARATION PLANTS+

A. Particulate

Source	Particle Size	Solids Loading	Chemical Composition	Particle Density	Electrical Resistivity	Moisture Content	Toxicity
1. Thermal Dryer							
a) Multi-louvre type	Cyclone Outlet $100 < 40$, $68 < 5$ $10 < 1$ (Coulter Counter)	2-200*	Coal Dust, Fly Ash				
b) Fluid-Bed type	Cyclone Outlet $90 < 10$, $80 < 5$ $40 < 2$ (Whitby Centrifuge Analysis) Also see Figure 20-5						

Source	Solubility	Wettability	Hygroscopic Characteristics	Flammability or Explosive Limits	Handling Characteristics	Optical Properties	Odor
1. Thermal Dryer		Hydrophobic		Fire or explosion hazards may exist both within drying chambers and cyclones, fans, and duct work beyond drying chamber.			

B. Carrier Gas

Source	Flowrate	Temperature	Moisture Content	Chemical Composition	Toxicity	Corrosivity	Odor	Flammability or Explosive Limits	Optical Properties
1. Thermal Dryer									
a) Flash type	a) 20-37			CO_2, N_2, O_2, CO, SO_2					
b) Conveyor type	a) 38-85								
c) Fluid-Bed type	a) 21-135 (22 plants) avg. 81.6	90-400							

+ See Coding Key, Table 5-1, Chapter 5, page 45, for units for individual effluent properties.

* Grains/actual cubic foot.

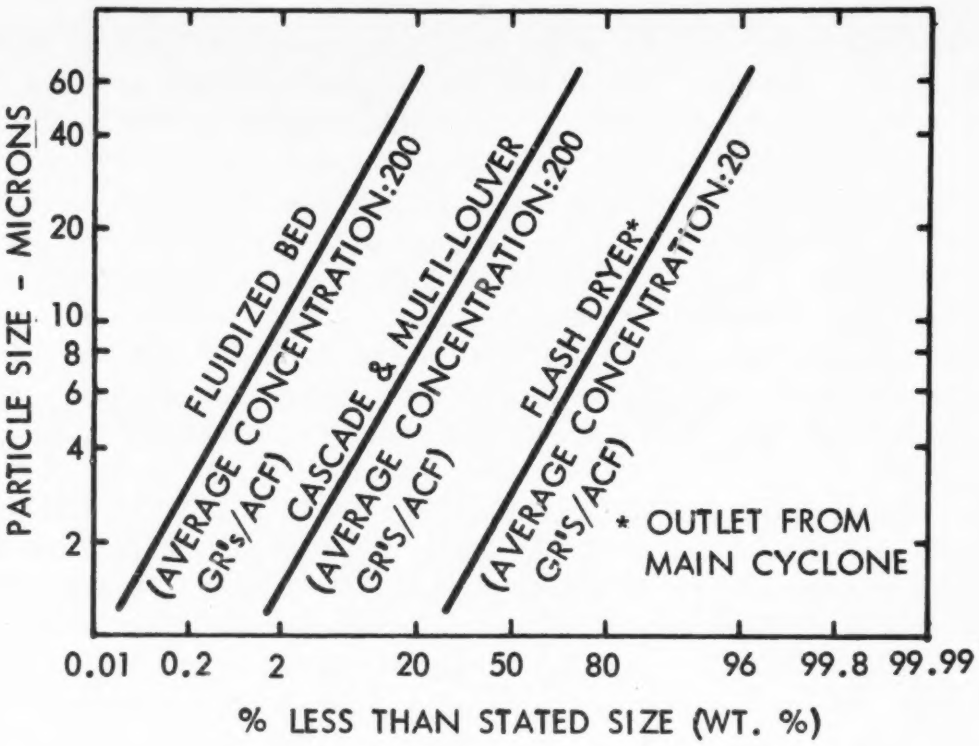

Figure 20-5 - Typical Particle-Size-Analysis Curves for Material Going to Cyclones (Coal Thermal Dryers)[16]

A recent NAPCA survey[5] indicated that all thermal coal dryers are equipped at least with dry cyclones, and about 50% also have low-energy wet scrubbers while about 4% have high-energy scrubbers.

The cyclones used as primary collectors can produce an exit solids loading of 3 to 3.5 grains/cu ft.[9] However, this loading can exceed 12 grains/cu ft in some cases.[10] The outlet grain loading from a low-energy wet scrubber (preceded by a cyclone) is usually about 0.15 grain/scf, although it may vary from 0.05 to 0.42 grain/scf.[5]

One coal company described the use of impingement-screen liquid scrubbing units but they have never operated satisfactorily because the impingement screens were easily blocked. These units had to be bypassed because of uncontrollable fires in them and the danger of explosion. They were later replaced with a different type of wet scrubber with a water usage rate of 3 gal/1,000 cu ft giving an exit grain loading of 0.035 to 0.048 grain/cu ft.

The installation of Venturi-type scrubbers at another coal company for cleaning the exhaust from a fluid-bed dryer is described in Reference 2. Installation was preceded by investigation of a 1,000 cfm test unit. Grain loading of the gases leaving the dry collectors was 3 grains/scf (see Figure 20-6). The outlet grain concentration loading from a Venturi scrubber as a function of pressure drop is shown in Figure 20-7. As a result of the tests, a commercial-size unit was installed for the 175 ton/hr dryer handling 95,000 cfm with a specified outlet loading of 0.05 grain/scf. This loading required 1,200 hp. for the combined pressure drop of 42 to 44 in. of H_2O of which about 20 in. is required for the Venturi. The installed cost was about $1.00/cfm of gases, although much existing equipment was utilized. If existing equipment had not been available, it was estimated that the cost would probably have been $1.50/cu ft.2/ These costs compare closely with general cost figures given in Appendix A.

Another recent Venturi scrubber installation is reported to have been installed at a cost of $0.90/acfm. This 35-in. w.g. Venturi scrubber was installed downstream of the cyclones, which served a 400 ton/day fluid-bed dryer, and handled approximately 200,000 acfm of gas. This installed cost of $0.90/acfm also compares very closely with the cost figures in Appendix A. However, this actual cost figure includes stainless steel construction for all surfaces in contact with water.14/

Careful consideration should always be given toward elimination or reduction of dust at its source. In connection with thermal dryer installations, it has often been found necessary to evaporate all water to attain successful operation of the dryer itself. This requirement leads to very high dust loadings to the collectors. It may be found possible to redesign or modify the thermal dryer to permit successful operation at a level of evaporation whereby 0.5 to 1.0% surface moisture remains on each coal particle. The dust loading to secondary collection equipment can sometimes be substantially reduced, providing increased collector efficiency and more satisfactory final emission to the atmosphere as well as reduced recirculation of ultra-fine coal in a plant water circuit.8/

20.5.2 Coal Refuse

Coal refuse, which is discarded as a part of the coal preparation, forms large piles which often catch on fire. A survey in 1962 identified 488 burning mine waste piles.11/ These are a source of particulate and gaseous pollution but no information has been located that would allow an assessment of the quantity of particulate emitted.

One of the methods used to control these coal refuse bank fires involves the use of high-pressure water nozzles followed by compaction. Overall cost has been estimated at $0.65/cu yard of material.12/

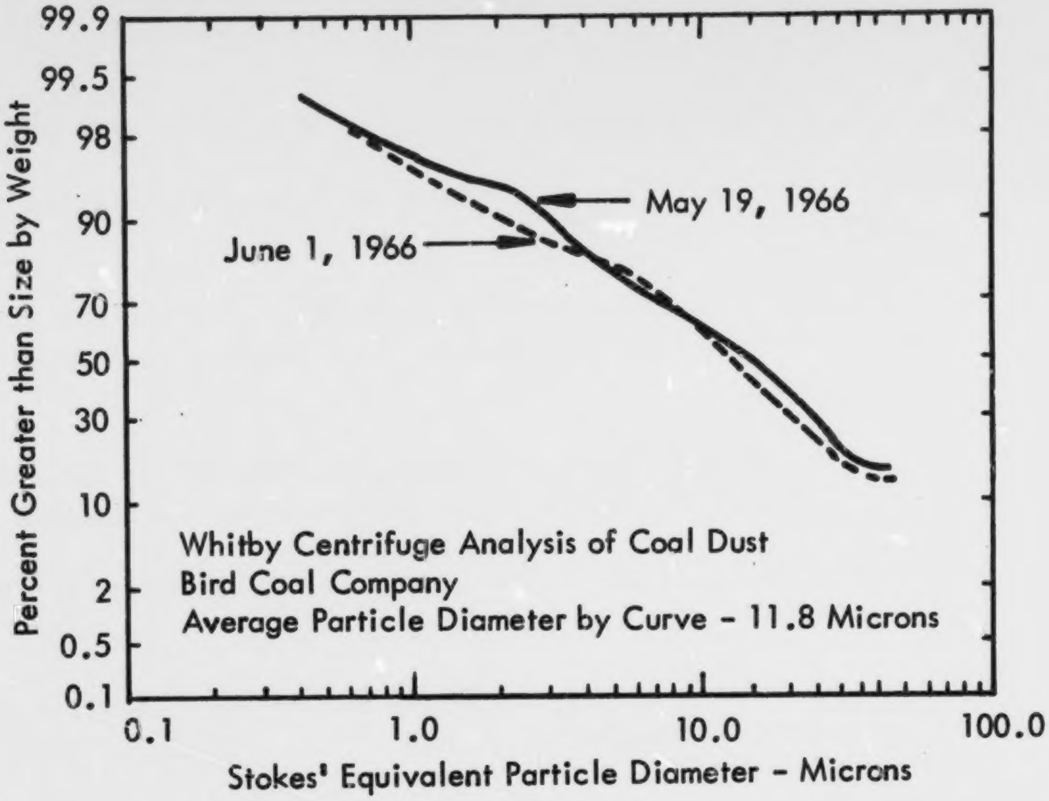

Figure 20-6 - Particle Size Distribution of Effluent[2/] (Fluid-Bed Dryer, Grain Loading, 3 Grains/scf)

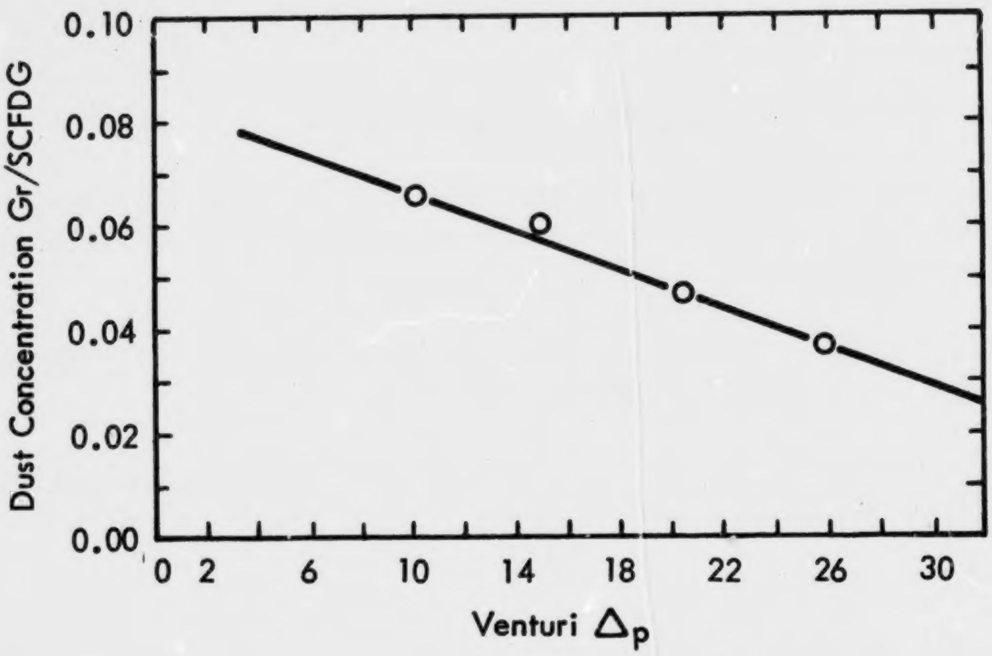

Figure 20-7 - Venturi Scrubber Performance on Coal Dryer[2/] Effluent (Inlet Loading, 3 Grains/scf)

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CHAPTER 21

CARBON BLACK

21.1 INTRODUCTION

Carbon black is ultrafine soot manufactured by the burning of hydrocarbons in a limited supply of air. This finely divided material (10 to 400 μ in diameter) is of industrial importance as a reinforcing agent for rubber and as a colorant for printing ink, paint, paper, and plastics.

Three basic processes currently exist in the United States for producing this compound. They are: the furnace process, accounting for about 83% of production; the older channel process, which accounts for about 6% of production; and the thermal process (1970 figures). Atmospheric pollutants from the thermal process are negligible since the exit gases which are rich in hydrogen are used as fuel in the process. In contrast, the pollutants emitted from the channel process are excessive and characterized by copious amounts of highly visible black smoke. Emissions from the furnace process consist of carbon dioxide, nitrogen, carbon monoxide, hydrogen, hydrocarbons, particulate matter, and some sulfur compounds. For the furnace process, collection equipment is an integral part of the process for collection of the product.

The manufacturing processes, particulate emission sources, particulate emission rates, effluent characteristics, and control practices and equipment are discussed in the following sections.

21.2 MANUFACTURING PROCESSES

The fundamental steps in carbon black (frequently referred to as black) manufacturing, regardless of the process used are:

1. Production of black from feed stock,
2. Separation of black from the gas stream, and
3. Final conversion of the black to a marketable product.

In the channel and furnace process, the black is produced by burning the feed stock. In the thermal process, the feed stock is thermally decomposed into black and hydrogen; there is no burning.1/

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21.2.1 Furnace Process

The furnace process is subdivided into either the gas or oil process depending on the primary fuel used to produce the carbon black. In both cases, gas (gas process) or gas and oil (oil process) is injected into a reactor with a limited supply of combustion air.

21.2.1.1 Gas-Furnace Process: Figure 21-2 shows a schematic flow diagram of the gas-furnace process. The furnace or reactor is refractory lined and is designed with special inlets or ports for natural gas and for air. An annular mixing orifice formed of refractory material is located within the converter. The flue gases, largely carbon monoxide, hydrogen, nitrogen, and water vapor, carry the hot carbon from the furnace through a long horizontal brick-lined flue, to a cooling tower where water sprays reduce temperatures from 1800 to 500°F. Agglomeration of the fine black particles occurs either in an electrostatic field provided by an electrical precipitator or by centrifugal force in cyclone collectors. When the electrical precipitator is used, about 30%, depending on the grade of black produced, is shaken off the electrodes into the collecting hopper attached to the bottom of the precipitator. The remainder of the flocculated black is caught, to a very large extent, in the cyclone collectors and bag filters which generally follow the precipitator. The gases including the carbon monoxide and condensable vapors (steam) are discharged through the stack of the final collector directly to the atmosphere. The black is carried to the finishing area by screw or pneumatic conveyors.1/

21.2.1.2 Oil-Furnace Process: The oil-furnace process is similar to the gas-furnace process except that the raw material used is oil instead of natural gas and the furnace design is also different. Each producer has developed and patented furnace designs. The design of the furnaces and burners constitutes an important part of carbon black technology. A flow diagram of the oil furnace process used at a large modernized plant is shown in Figure 21-1.

21.2.2 Channel Process

A schematic flow diagram of the channel process is shown in Figure 21-3. A typical channel plant may cover many acres and may be composed of several hundred steel buildings (called "burner houses" or "hot houses") housing some 2,000 to 4,000 flames and the appropriate number of channel irons, upon which the flames impinge and deposit carbon black.

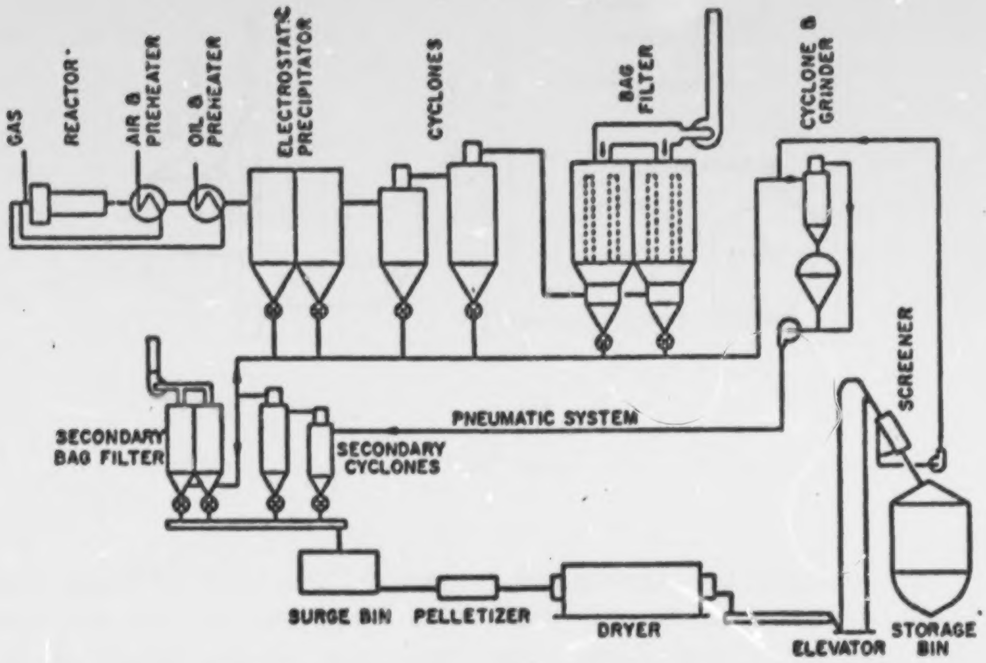

Figure 21-1 - Flow Diagram of Oil-Furnace Process[1]

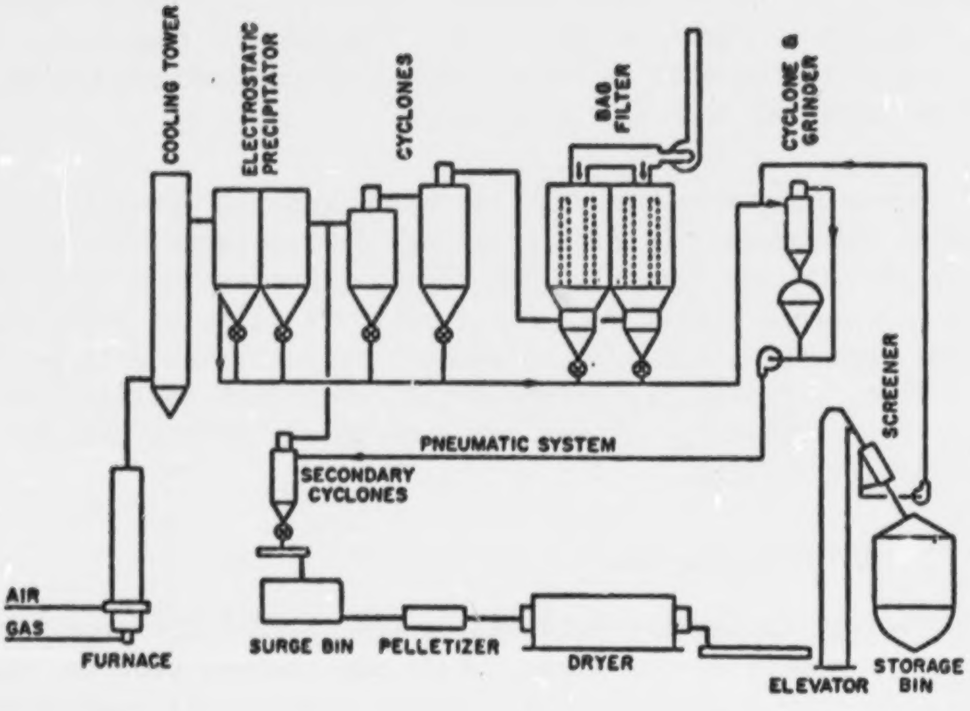

Figure 21-2 - Flow Diagram of Gas-Furnace Process[1]

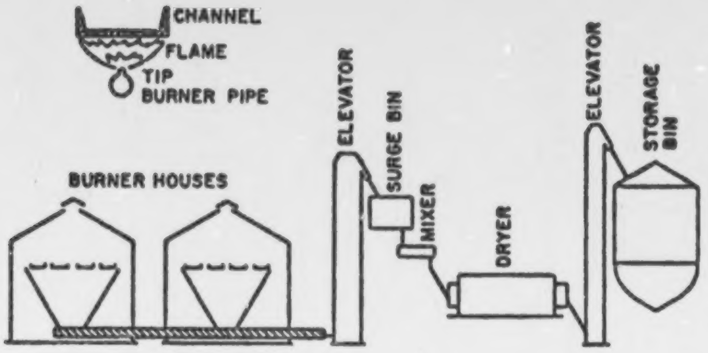

Figure 21-3 - Flow Diagram of Channel Process

Air is supplied through openings at the base of each building. The spent gases and products of combustion pass out of the hot house through openings and stacks in the roof. Gas rates are on the order of 45 to 80 cu ft/24-hr day/burner tip, and may range from 150,000 to as high as 260,000 cu ft/24-hr day/hot house. Combustion is controlled by natural draft openings in the top and bottom of each house. Draft control is visual and dependent upon the skill of the operators. A large excess of air holds the temperature of the house below 1000°F. However, this large excess of air does not completely burn the natural gas because the combustion time from the gas tip to the channel is very short, and complete mixing of air and gas in this interval does not occur.[1,2]/

Screw conveyors pick the black up from the various houses and convey it to the processing area where an air separator removes particles of grit (hard calcined carbon). The fluffy black is then further processed through a high-speed hammer mill (micropulverizer) to break up lumps that form in the conveyors, and also to render any remaining grit particles extremely fine. It also pulverizes oversize product pellets that recycle from downstream screening. The black then passes to the pelletizing step and subsequent packaging.

21.2.3 Thermal Process

Thermal blacks are produced by the thermal decomposition of natural gas in the absence of air or flame. (1) The thermal process, Figure 21-4, comprises: (1) the cracking units (termed generators) consisting of checkerwork furnaces; (2) coolers; (3) carbon collectors; and (4) packing. The furnaces are 12 to 14 ft. in diameter and 25 to 35 ft. high, and consist of a riveted steel shell, insulated and lined with refractory brick and filled with checker brick similar to that of a blast-furnace stove.[3,4]/

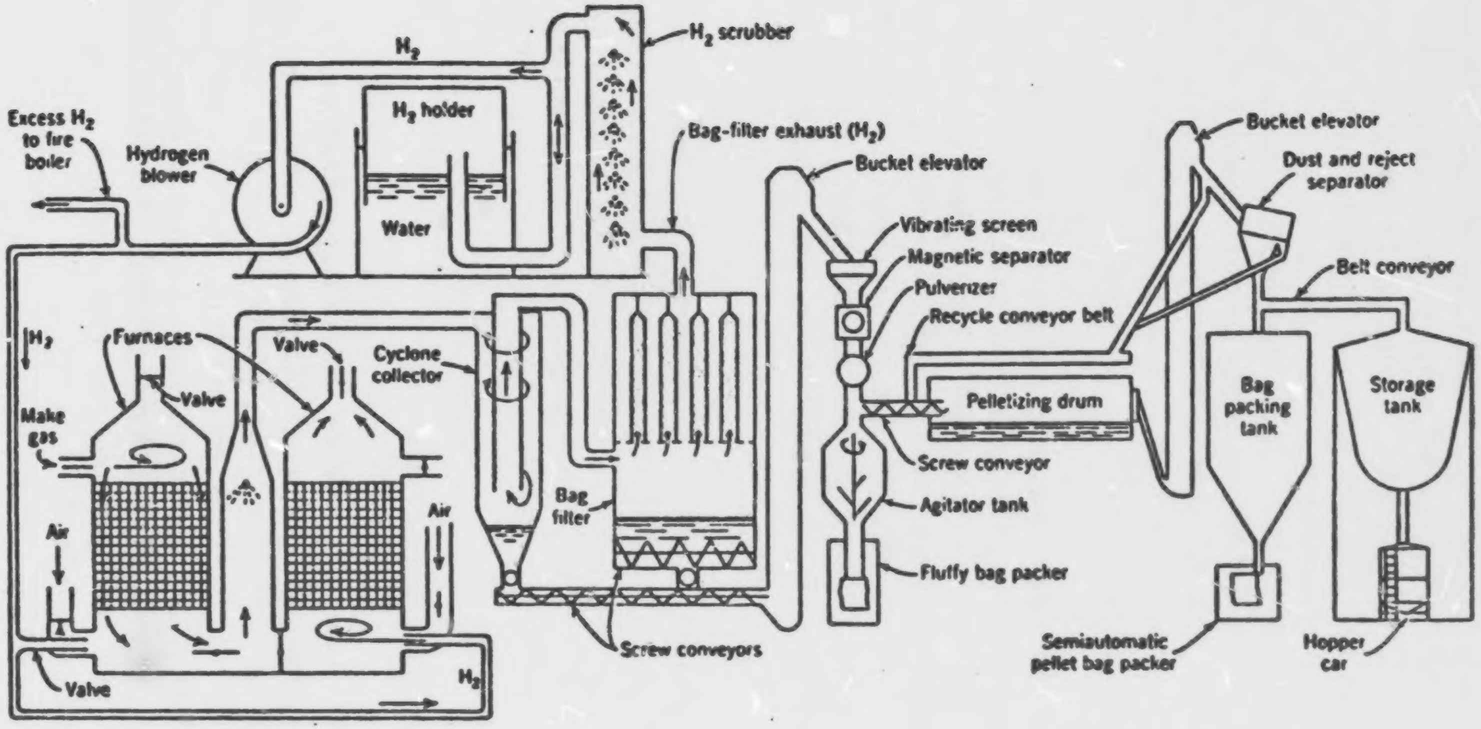

Figure 21-4 - Flow Diagram of Thermal Process1/

Thermal black differs from other carbon black operations in that it is cyclic rather than continuous.[5] The process is intermittent, the checkerwork being first heated to 2400 to 2800°F by the complete combustion of a blast of natural gas and air introduced at the bottom. When the bricks are brought up to the required temperature, the stack (vent to the atmosphere) is closed and natural gas is admitted from the top of the furnace for the decomposing part of the cycle. Thermal black is produced when the heat from the brickwork decomposes the gas into a smoke of thermal carbon plus quantities of hydrogen.[6] When the bricks become cool, the natural gas flow is shut off and the remaining carbon smoke is flushed out into the cyclone separators. The complete cycle for a single generator requires approximately 10 min. Of this time, about half is required for heatup and half for the cracking process.[5]

The effluent gas from the generator, which is on the production cycle, consisting of about 90% hydrogen, 6% methane, and a remaining complex mixture of higher hydrocarbons, carries the suspended black.[7] The smoke from the furnace is passed by countercurrent flow through a water-sprayed cooling tower to cool the smoke to about 125°C. This temperature allows it to be safely filtered through the cloth bags in the collectors and yet not wet either the bags or the carbon. Recovery is about 40 to 50% of the carbon in the fuels.

The collected black is transported by screw conveyors to the processing area where it is passed through a magnetic separator, screen, and hammer mill. It may then be packed through an auger packer as fluffy black in 25 or 50 lb. paper bags, or passed through pelletizing equipment, which transforms the fluffy black into a free-flowing product.

21.3 EMISSION SOURCES AND RATES

The most important factor affecting emissions is the basic manufacturing process and its inherent efficiency. Thus, emissions from the channel black process are excessive, while those from the thermal process are negligible. Particulate emissions from the furnace process are affected by the type of collection equipment used. Gaseous emissions are largely determined by the overall yield, type of fuel (that is, liquid or gas), the reaction time and temperature, the ratio of gas to oil in the feed, and the amount of combustion air.[8]

Additional emissions may result from the conveying, grinding, screening, drying, and packaging operations at a carbon-black plant. Poorly designed or maintained equipment can result in leaks and spills. Spillages of the fluffy black before pelleting are the source of pollution.

After pellets have ceased to form in the dry pelleting process the drum is emptied, and reloaded with fresh loose black, and reseeded, and then pelleting resumes. The emptying of the drum will naturally result in black spillage.

Maintenance operations will often result in carbon-black spillage. The cleaning of clogged screens, located either at the top of the storage tank into which the finished black is screened or at the pelleting section where oversized pellets are screened out, causes black to be discharged into the atmosphere. Whenever a production line is plugged, the remedial measures are either to pound the line or use a vibrator. If this proves ineffective, high-pressure air is used to dislodge the black. Carbon black is generally emitted to the atmosphere in this operation.

Carbon black is so finely divided that whenever a leak develops in plant equipment, such as in the conveyor system, or in the bins, or at the bagging equipment, black will seep out into the atmosphere.

Table 21-1 summarizes emission rates for carbon black manufacture. Emission factors for the channel black process are questionable because of a complete absence of emission data.8/ Emissions due to conveying, grinding, etc., were not estimated because of the variability of these emissions.8/ Particulate emissions currently total about 93,000 tons. The channel process, which accounts for only about 6% of the total production, emits nearly 90% (82,225 tons) of the particulates.

21.4 CHARACTERISTICS OF EFFLUENTS FROM CARBON-BLACK MANUFACTURE

Limited data were found on the chemical and physical properties of effluents from carbon-black plants. Available data are summarized in Table 21-2. The particle size of the emitted carbon black is extremely fine (i.e., of the order 0.1-0.5 μ). The carbon monoxide content of the offgas may be as high as 20% by volume.

21.5 CONTROL PRACTICES AND EQUIPMENT

The channel process emits large quantities of carbon because no way has yet been developed to separate the escaping black and avoid upsetting the burning conditions, which in turn would drastically affect yield and quality.1/ Production by the channel process has declined over the years, and at present only 3 plants are known to be in operation.9/ These three plants produce a total of approximately 71,500 tons/yr representing about 6.0% of the total carbon black produced in the U. S.

TABLE 21-1

PARTICULATE EMISSIONS FROM THE MANUFACTURE OF CARBON BLACK

Source	Quantity of Material	Emission Factor	Application of Control C_c	Efficiency of Control C_t	Net Control $C_c \cdot C_t$	Emissions (tons/yr)
I. Channel process	71,500 tons, carbon black	2,300 lb/ton product	0.0	0.0	0.0	82,000
II. Furnace process						
A. Gas	156,000 tons, carbon black	60 lb/ton product*	---	---	---	5,000
B. Oil	1,180,000 tons, carbon black	10 lb/ton product*	---	---	---	6,000
					Total	93,000

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* Controlled emission factor. Cyclone followed by scrubber; 97% efficiency.

** Controlled emission factor. Fabric filter; 99.5% efficiency.

TABLE 21-2

EFFLUENT CHARACTERISTICS - CARBON BLACK[+]

A. Particulate

Source	Particle Size	Solids Loading	Chemical Composition	Particle Density	Electrical Resistivity	Moisture Content	Toxicity
I. Thermal Process	0.1-0.5		Carbon	1-5 lb/ft^3 (Bulk Density)			
II. Furnace Process (oil)	0.02-0.4	10-50 (Reactor Outlet)	Carbon				

B. Carrier Gas

Source	Flowrate	Temperature	Moisture Content	Chemical Composition	Toxicity	Corrosivity	Odor	Flammability or Explosive Limits	Optical Properties
I. Furnace Process									
a. Oil	a) 3-5 b) 120-150			Typical Composition CO_2: 3.0 O_2: 0.3 CO: 6.0 H_2: 8.0					
b. Gas	a) 3 b) 360			C_2H_2: 0.5 CH_4, C_2H_6 etc.: 0.2 N_2: 41 H_2O: 40					

[+] See Coding Key, Table 5-1, Chapter 5, page 45, for units for individual effluent properties.

For the furnace process, collection equipment is an integral part of the process for collection of the product. The types of equipment commonly used for effectively separating and collecting finely divided black from a gas stream are agglomerators, electrostatic precipitators, cyclone separators, scrubbers, and baghouses.[1]

In old plants, the black-laden gases are first cooled to about 450 to 550°F, and then passed through a dry electrostatic precipitator which agglomerates the black. The increased diameter and density of the agglomerated black permits it to be removed effectively from the gas stream by using several cyclone separators. Together these have a recovery efficiency of 85 to 90%, leaving about 10% of the initial carbon in the off-gases. Collection or removal of nearly all the remaining 10% is accomplished when the off-gases are passed through either a bag filter to give 99% recovery or a wet-scrubber system with 97 to 98% collection overall. The scrubber system may comprise water scrubbing and wet electrostatic precipitation or washing in a slot scrubber followed by a wet cyclone scrubber. In order to recover the black, the slurry is circulated back to the reactors where it is used for quench. The black is thus re-entrained in the smoke and recovered.

The electrostatic precipitator is rapidly disappearing from use in the carbon-black industry. Even at some older plants they are no longer in operation, since they have been shut off to save operating and maintenance expenses. They are not energized, and no carbon black is removed from them. The current trend is to do without electrostatic precipitators in new furnace-black plants. The trend is to a mechanical agglomeration device (i.e., cyclones) placed ahead of bag filters. When the older plants were built, suitable filters had not yet been developed, and the use of cyclones by themselves was inadequate.

In recent years, the carbon-black industry turned to agglomeration apparatus of lower first cost and of equivalent or superior performance compared with the electrostatic precipitator. Accordingly, in most plants, the black-laden gases, cooled to about 550°F, enter a series of large diameter cyclones (usually four) which separate about 70% of the carbon. The gases with the remaining black may be cooled further to about 360°F. They are then passed to a bag filter which separates the remaining black from combustion gases for an overall recovery of 99+%.

In some plants, cyclones (as well as electrical precipitators) have been eliminated and the design for carbon-black separation calls for a system with an agglomerating device and a single bag filter connected in series.[1]

21.5.1 Control Equipment

21.5.1.1 Wet Scrubbers: Wet scrubbers, despite their high recovery efficiency, have very limited use in the United States for separating carbon black from a gas stream. Nor are wet electrostatic precipitators currently in use by the carbon black industry in this country.

21.5.1.2 Cyclone Separators: Two main types of cyclone separators are utilized in carbon-black collection: (1) medium-efficiency or high-capacity cyclones, generally of fairly large diameter and used singly; (2) modern high-efficiency, high-velocity cyclones, usually nested in groups of two, four, eight, or more. Primary cyclones are of various sizes. A typical cyclone used (old design) is 11 ft. in diameter and 35 ft. high. The cyclone based on the new design (high efficiency) is 6 ft. in diameter and 15 ft. high. Secondary cyclones are only 54 in. in diameter and 10 to 12 ft. high. Cyclones have an agglomerating effect on the black because of the centrifugal motion created within the equipment.

21.5.1.3 Baghouses: In bag filters, the black-laden gas stream enters the open bags at the bottom and passes through the cloth, depositing solids on the cloth, and the clean gas discharges to atmosphere. The bags are cleaned by reversing the flow of the gas and repressuring. The temperatures involved rule out the use of cheap reliable filter media, such as cotton, wool, and "orlon." The maximum working temperature of these materials is about 275°F. These filters faced a considerable corrosion problem until bags of woven glass fabric made from staple yarn were introduced. Filtration can thus be carried out at temperatures up to 550°F. However, the brittle fibers cannot stand up to the shaking required to free the black collected on the cloth, and the cloth wears out quickly. To solve this problem, cloth manufacturers coat the fibers with resins and silicone oils to help fibers slip over each other more easily.

In carbon-black manufacture, bag filters are eliminating the need of electrostatic precipitators, scrubber units, and even cyclone separators.

Filter-bag life varies greatly depending on several factors, such as gas-to-cloth ratio (or how heavily the cloth is loaded), the grade of black being produced, and the type of cloth used. Typical bag life is about 12 months.

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CHAPTER 22

PETROLEUM REFINING

22.1 INTRODUCTION

The petroleum industry can logically be divided into three major divisions: production, refining, and marketing. Production includes the operations involved in locating and drilling oil fields, removing oil from the ground, pretreatment at the well site, and transporting the crude to the refinery. Refining is limited to operations necessary to convert the crude into salable products. Marketing involves the distribution and sale of finished petroleum products. Only the refining operations will be considered in this discussion.

The emission of particulate matter from refineries may originate from catalyst regeneration, decoking operations, airblown asphalt stills, sludge burner, boilers, process heaters and incinerators.[17] Flare systems may also produce particulate emissions because of formation of carbon particles but this is a result of the combustion process at the flare.

Production processes, particulate emission sources, particulate emission rates, effluent characteristics, and control practices and equipment for petroleum refining are discussed in the following sections.

22.2 EMISSION SOURCES

Refineries vary greatly in both the quantity and type of emissions. The most important factors affecting refinery emissions are crude oil capacity, air pollution control measures in effect, general level of maintenance and good housekeeping in the refinery, and the processing scheme employed. The emissions which may contribute to air pollution are sulfur oxides, nitrogen oxides, hydrocarbons, carbon monoxide, and malodorous materials. Other emissions of lesser importance include particulates, aldehydes, ammonia, and organic acids. Table 22-1 indicates potential sources of the various contaminants from refineries and emphasizes the variety of equipment and operations which must be considered in a complete survey of refinery emissions.[15]

Many processes and operations in oil refineries necessitate the use of high-pressure steam, or require feedstock at an elevated temperature. A wide variety of boilers and process heaters are used to fill these needs. Heaters may be of unique design, although most units are the box, or cylindrical, vertical type. Boilers are generally of conventional design.

TABLE 22-1

POTENTIAL SOURCES OF SPECIFIC EMISSIONS FROM OIL REFINERIES[15]

Emission	Potential Sources
Oxides of sulfur	Boilers, process heater, catalytic cracking unit regenerators, treating units, H_2S flares, decoking operations
Hydrocarbons	Loading facilities, turnarounds, sampling, storage tanks, waste-water separators, blow-down systems, catalyst regenerators, pumps, valves, blind changing, cooling towers, vacuum jets, barometric condensers, air-blowing, high-pressure equipment handling volatile hydrocarbons, process heaters, boilers, compressor engines
Oxides of nitrogen	Process heaters, boilers, compressor engines, catalyst regenerators, flares
Particulate matter	Catalyst regenerators, boilers, process heaters, decoking operations, incinerators
Aldehydes	Catalyst regenerators
Ammonia	Catalyst regenerators
Odors	Treating units (air-blowing, steam-blowing), drains, tank vents, barometric condenser sumps, waste-water separators
Carbon monoxide	Catalyst regeneration, decoking, compressor engines, incinerators

The fuel may be refinery gas, natural gas, heavy fuel oil, coke, or combinations, depending on economics and operating conditions. Particulate emissions from boilers and process heaters are included in the stationary combustion sources discussed in Chapter 6.

During catalytic cracking, reforming, and hydrogenation, coke formed on the surface of the catalyst is burned off in regenerating vessels by controlled combustion. The flue gases from the catalyst regenerator may contain fine catalyst dust, and the products of combustion of the coke may include some of the impurities contained in the charging stock. Cracking unit regenerators are usually large, operate continuously, and are potential sources of dust, carbon monoxide, hydrocarbon (nearly all methane), and sulfur-oxide emissions. Reforming and hydrogen treating units usually regenerate catalysts intermittently and are a less important source of emissions.[15/]

The catalyst regenerator is a major particulate emission source, and it is discussed in more detail in the following sections.

22.2.1 Catalyst Regenerator

Catalytic cracking is the backbone of the modern refinery. The capacity of these units amounts to about 4 million barrels per day, equivalent to about 40% of total refinery crude capacity. Cracking over a catalyst, usually an alumina-silicate, is accomplished at slightly greater than atmospheric pressures and about 900°F. It gives a higher gasoline yield and better quality gasoline than thermal cracking. The charge stock is usually gas oil, a distillate intermediate between kerosene and fuel oil. Catalytic cracking yields a "synthetic crude" which is separated into gaseous hydrocarbons, gasoline, gas oil, and fuel oil.

During the cracking process, which is usually continuous, coke deposits on the catalyst and is burned off in separate regenerating vessels.

Catalytic cracking units may be classified according to the method used for catalyst transfer. There are four main methods: (1) fixed-bed, utilizing a number of reaction-regeneration chambers in a batch-type operation, (2) moving-bed, (3) fluidized-bed, and (4) a once-through catalyst system which does not attempt catalyst regeneration. Fixed-bed and once-through systems are no longer used to any great extent. The moving-bed system, typified by the Thermofor Catalytic Cracking Units (TCC) and the Houdriflow Units, and the fluidized-bed or Fluid Catalytic Cracking Units (FCC), are now almost universally used in refinery operations.

A typical flow diagram of a fluid cracking unit is shown in Figure 22-1. In the production of high-octane gasoline, oil and powdered catalyst are mixed in a reactor. Spent catalyst, containing residual carbon (or coke) from the catalytic cracking process taking place in a reactor, is mixed with combustion air and fed to the regenerator in order to reactivate the catalyst by burning off the coke or residual carbon formed on the catalyst during the cracking process. After regeneration, the hot incinerated catalyst is mixed with crude oil and is transported back to the reactor where the oil is distilled off ("cracked") and the cycle repeated.

The gaseous products of combustion from the top of the regenerator are exhausted through a series of mechanical collectors which return their catch directly to the fluid bed. The finer fractions of the catalyst escape along with the discharged gas. The exhaust gases may be further cleaned with additional cyclones or an electrostatic precipitator.

In order to protect the collectors and other down-stream equipment against high-temperature damage, temperature control water sprays are used in the combustion zone over the fluid bed. The regenerator is followed by waste-heat steam boilers in order to recover some of the heat energy and reduce the gas temperature. Further gas cleaning is then accomplished by electrostatic precipitators in many plants.

Large amounts of carbon monoxide gases are discharged with the regeneration flue gases of an FCC unit. The carbon monoxide waste-heat boiler is a means of using the heat of combustion of carbon monoxide and other combustibles, and the sensible heat of the regeneration gases. Regeneration gases from an FCC unit are normally delivered to the inlet of the CO boiler at about 1100°F and 2 psig.[4]

22.3 CATALYST REGENERATOR EMISSION RATES

Due to the high extent of control, emission rates from catalytic cracking units could not be calculated using the methods of emission factors. Available data indicate that one 6,000 BPSD (barrel/stream day) FCC unit emits 0.135 ton of dust per day based on 0.016% dust in the air stream out of the final separator.[13] The total capacity of FCC units is 3,609,000 BPSD. By direct ratio:

$$\text{Emission from FCC} = \frac{3,609,000}{6,000}\ (0.135\ \text{ton/day})$$

$$= 81\ \text{tons/day} = 24,000\ \text{tons/year}$$

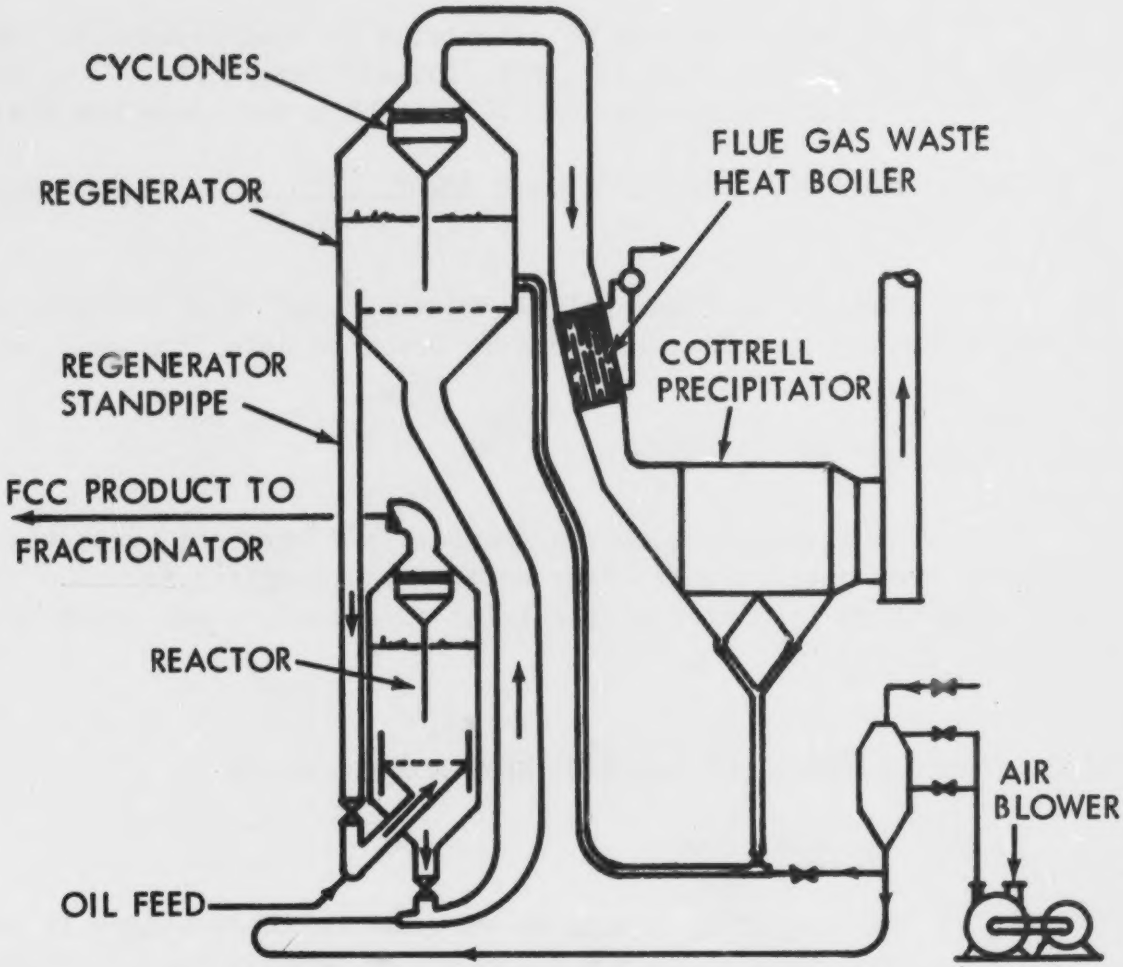


Figure 22-1 - Flow Diagram of Fluid Cracking Unit[10]

The emissions may be calculated by another method. Information from Reference 14 indicates catalyst "losses" range from 0.05-0.1 lb/bbl fresh feed. Using the average of 0.075 lb/bbl, the emissions would be:

$$(0.075\ \frac{\text{lb.}}{\text{bbl.}})(3.609 \times 10^6\ \frac{\text{bbl.}}{\text{day}})(330\ \frac{\text{day}}{\text{yr}})(\frac{\text{Ton}}{2{,}000\ \text{lb.}}) = 44{,}700\ \text{tons/year}$$

The latter figure of 44,700 tons/year is probably more representative because the former figure is based on data from only one plant.

22.4. EFFLUENT CHARACTERISTICS

Available data on the chemical and physical properties of effluents from catalytic cracking units are summarized in Table 22-2. Particle size of particulates at the inlet of secondary collectors ranges from 10-45 wt. % less than 2 μ.

22.5. CONTROL PRACTICES AND EQUIPMENT FOR FCC UNITS

22.5.1 Cyclones

The use of cyclones, in one, two or three stages is common practice for control of dust from FCC units. In typical installations, multistage cyclones are located in the regenerator vessel for catalyst recovery and re-utilization. In some cases external cyclones are installed to reduce the particulate content of the flue gases. Catalyst dust losses from the regenerator equipped with internal cyclones and, in some cases, supplemented by external cyclone equipment can range in the order of 100 to 350 lb/hr.

The maximum efficiency which can be obtained with external cyclones would depend on the efficiency of the preceding cyclones, but it may range as high as 90% recovery of the solids leaving the preceding vessel. The installed cost for a set of external cyclones designed for maximum efficiency will run between \$1.25 and \$1.75/acfm of gas leaving the vessel (before the pressure regulating valve) for units discharging between 40,000-60,000 acfm of gas. The cost of a system designed to recover approximately 60% of the solids leaving the vessel would be about half as much as the system designed for maximum efficiency.7/ These costs are two to three times higher than the general cost figures in Appendix A but installation in a refinery FCC unit is a special application involving different materials of construction, higher pressures and more difficult installation problems.

TABLE 22-2

EFFLUENT CHARACTERISTICS - PETROLEUM REFINING+

A. Particulate

Source	Particle Size	Solids Loading	Chemical Composition	Particle Density	Electrical Resistivity	Moisture Content	Toxicity
Petroleum Refining							
Catalytic cracking unit.	Cyclone Inlet: 21-45 < 2 avg. 27 < 2 33-72 < 5 avg. 49 < 5 47-89 < 10 avg. 64 < 10 Precipitator Inlet (Bahco) 10 < 2, 20 < 4 35 < 8, 40 < 10 62 < 25	5-25	Dependent on catalyst type. Varies from natural earth clays to the synthetic varieties which are mostly oxides of silica and alumina.	2.2-3.1	See Figure 22-2		

B. Carrier Gas

Source	Flowrate	Temperature	Moisture Content	Chemical Composition	Toxicity	Corrosivity	Odor	Flammability Limits	Optical Properties
Catalytic cracking unit	(a) 70.5 (1 plant)	Outlet Temp. 1050-1150	10-30	Dry: Flue Gas CO_2: 6-9 CO: 6-7 O_2: 1-3 N_2: 81-87 SO_2: trace Hydrocarbons: trace	Contains CO				

+ See Coding Key, Table 5-1, Chapter 5, page 45, for units for individual effluent properties.

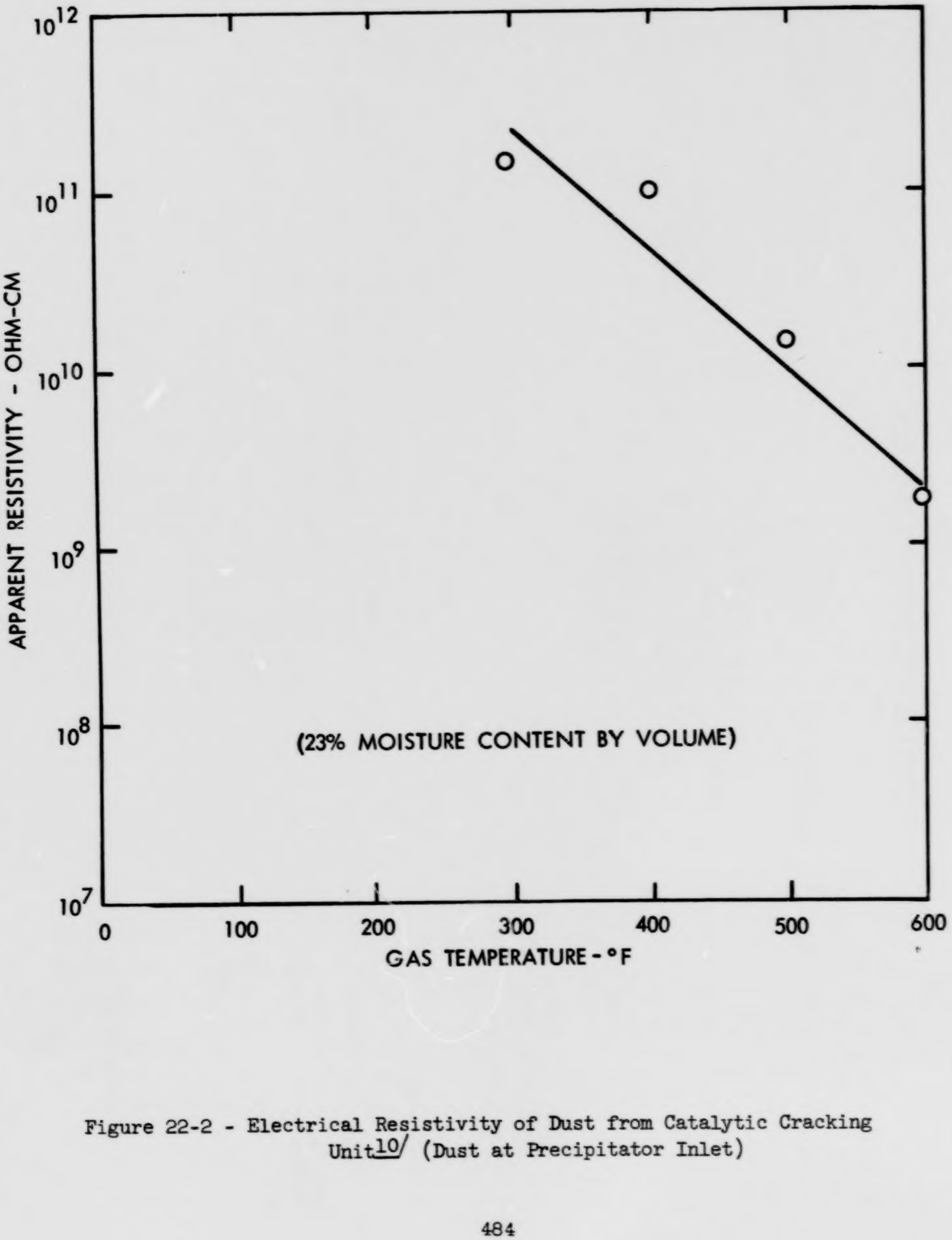


Figure 22-2 - Electrical Resistivity of Dust from Catalytic Cracking Unit[10] (Dust at Precipitator Inlet)

The application of a special third-stage, high-efficiency, multiple-tube, swirl-vane type centrifugal separator to FCC units is described in two recent articles.[8,9] This third-stage separator allows the main body of the gas stream to be utilized in a turboexpander without serious problems.

22.5.2 Electrostatic Precipitators

A third mechanical cyclone external to the regenerator improves dust removal but generally it is not sufficient to comply with stringent emissions standards. Electrostatic precipitators have been used for this service with good success and some refiners have reported catalyst dust losses as low as 40-60 lb/hr, although typical current installations have higher emission rates.[3] The precipitator may be preceded by a power recovery turbine or a CO boiler. Schematic flow diagrams are shown in Figures 22-3 and 22-4.[6]

The fluid-bed catalytic cracking units may emit 0.0009% of the catalyst circulated when equipped with electrical precipitators, or 0.005% when not so equipped. This may be contrasted with moving-bed catalytic crackers that emit 0.002% of the catalyst circulated when equipped with centrifugal separators.[2]

Reference 12 reports on a study of stack losses from a FCC unit equipped with cyclones and an electrostatic precipitator. The catalyst carryover and the weight percentage of 0-20 μ material in the carryover are shown in Figures 22-5 to 22-7 for the operating conditions given in Table 22-3. Figure 22-5 shows that catalyst carryover from the cyclone increases rapidly as the quantity of fines in the air stream increases. It was therefore concluded that carryover of material to the precipitator, and hence stack loss, may be controlled by regulation of the amount of fines in the unit. Figure 22-6 is a calculated curve of stack loss as a function of particle size distribution of catalyst carried over from the cyclones for three different precipitator collection efficiencies (computed from Figure 22-5 and a fractional efficiency curve). Figure 22-7 is a calculated curve of size distribution of the stack loss, derived in the same manner as Figure 22-6.[12]

TABLE 22-3

TYPICAL PLANT OPERATING CONDITIONS

Fresh feed rate to reactor, bbl/day	25,000
Air rate, lb/hr	235,000
Coke burning ratio, lb/hr	20,000
Fresh catalyst-addition rate, tons/day	6.1
Fresh catalyst type	MSA-2

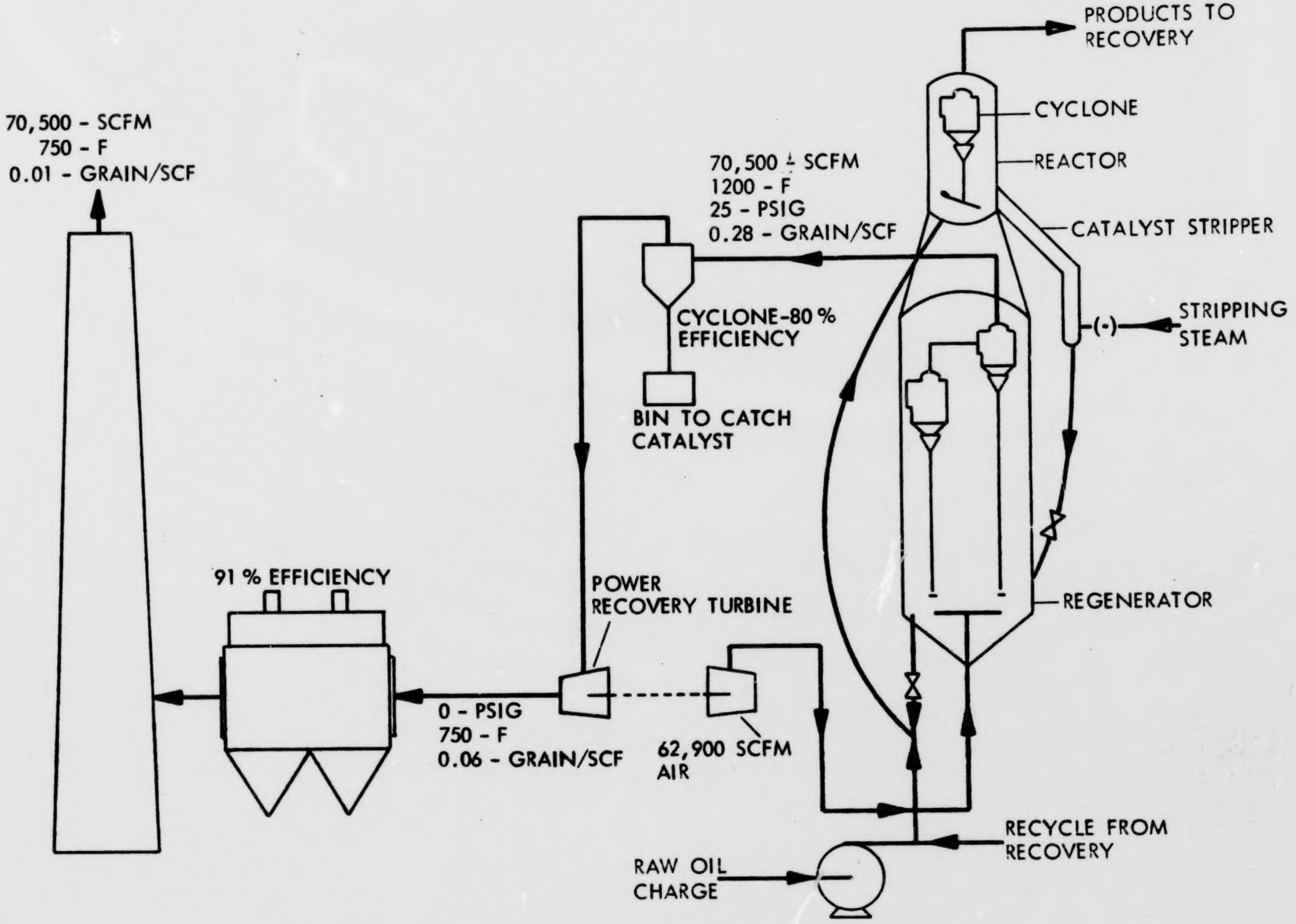


Figure 22-3 - Schematic Flow for Precipitator Installed After Power-Recovery Turbine[6]

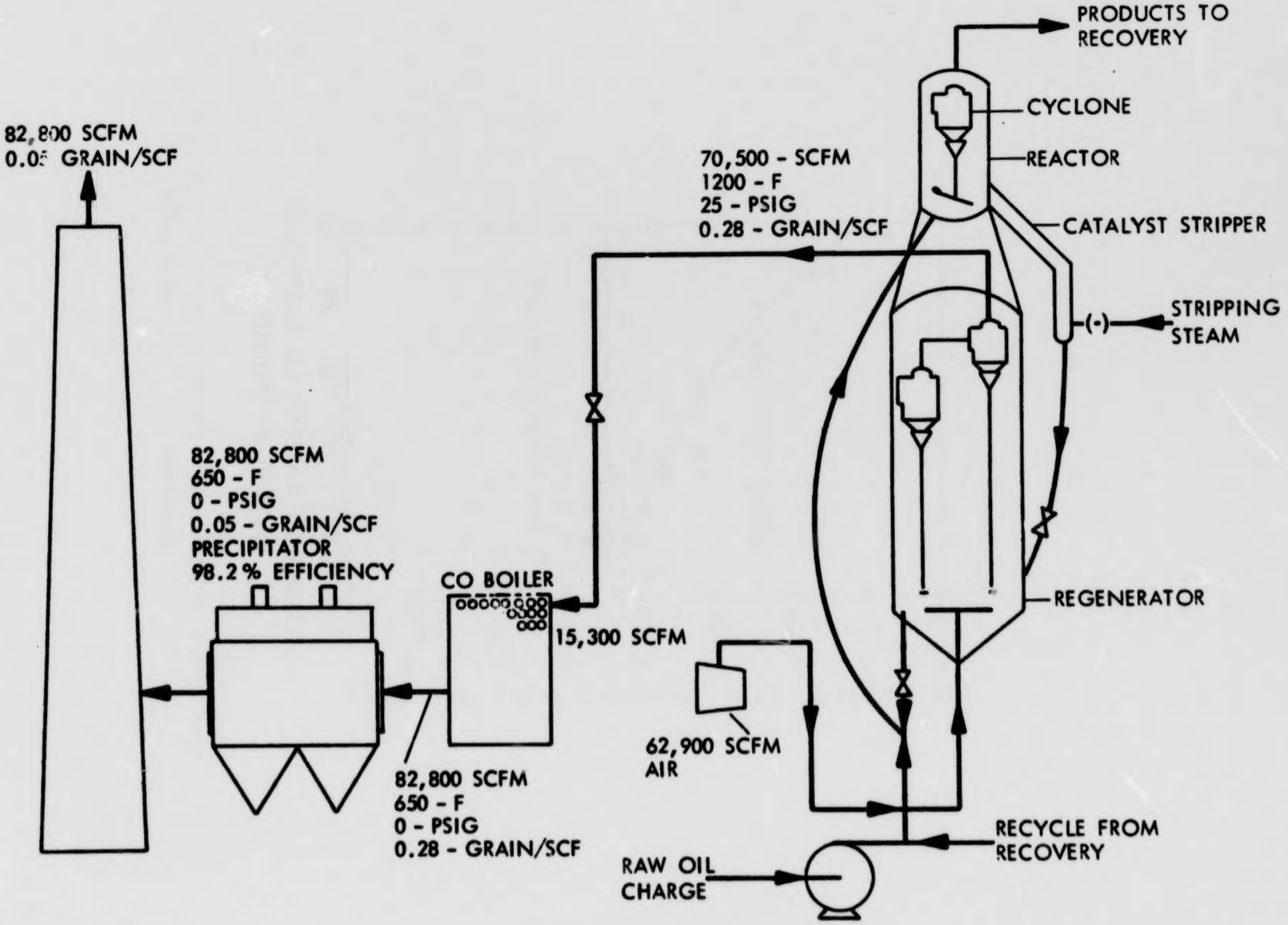


Figure 22-4 - Schematic Flow for Precipitator Installed After CO Boiler[6]

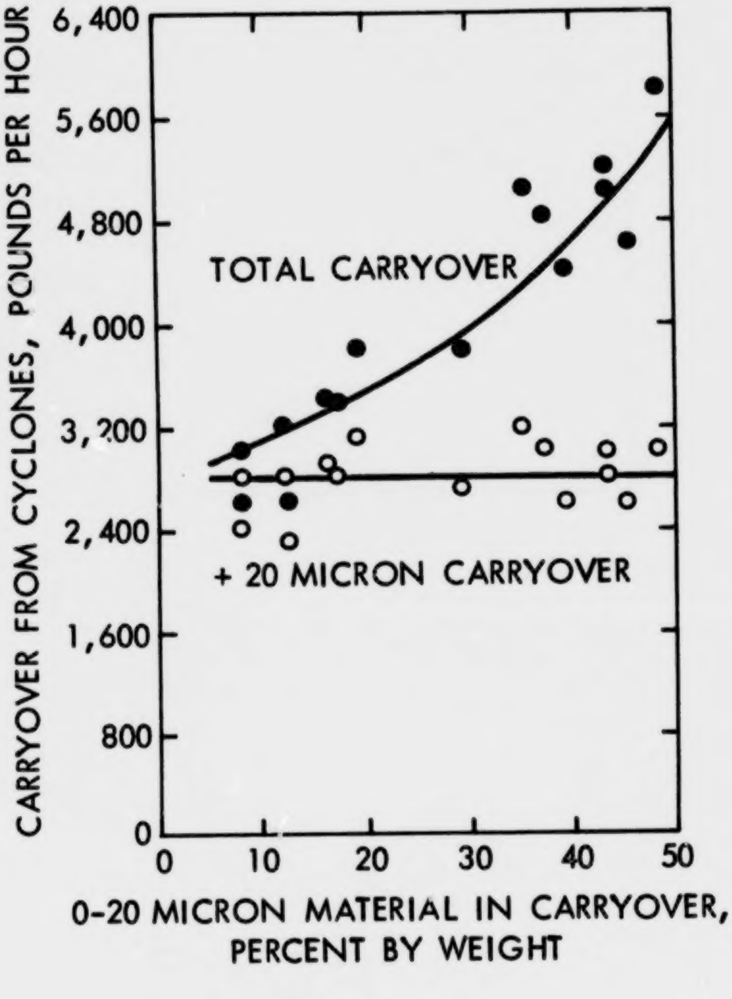
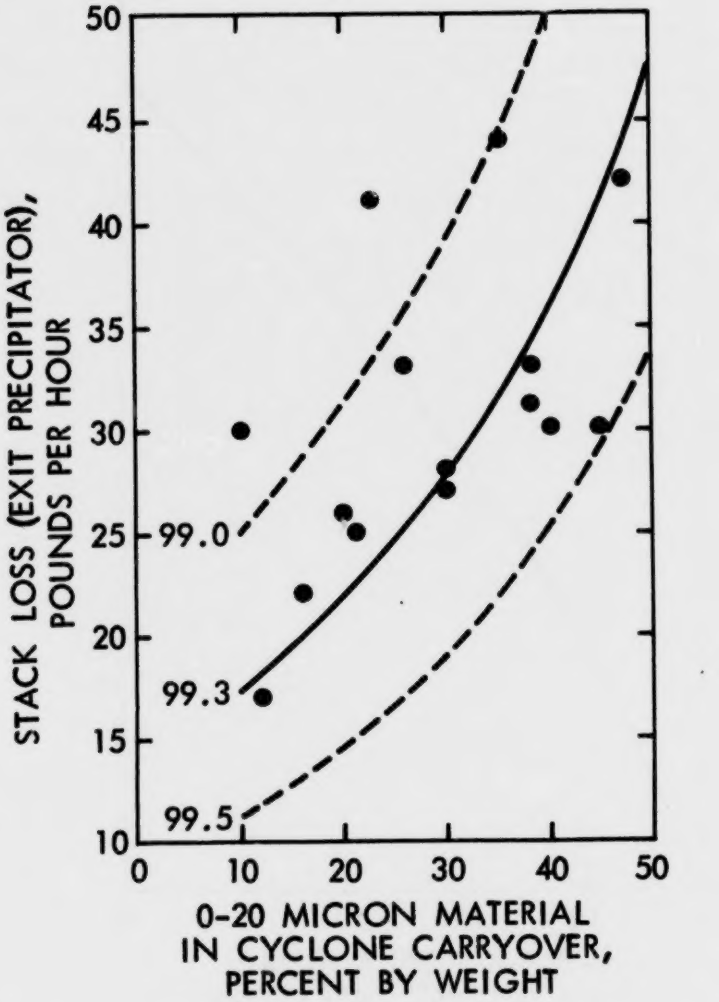


Figure 22-5 - Relationship Between Quantity of Catalyst Carryover and Particle Size[12]



NOTE: THE FIGURES AT THE LOWER END OF EACH CURVE ARE AVERAGE COLLECTION EFFICIENCY AT 30 % 0-20 MICRON MATERIAL IN CYCLONE CARRYOVER

Figure 22-6 - Calculated Stack Losses as a Function of Particle-Size Distribution of Cyclone Carryover[12]

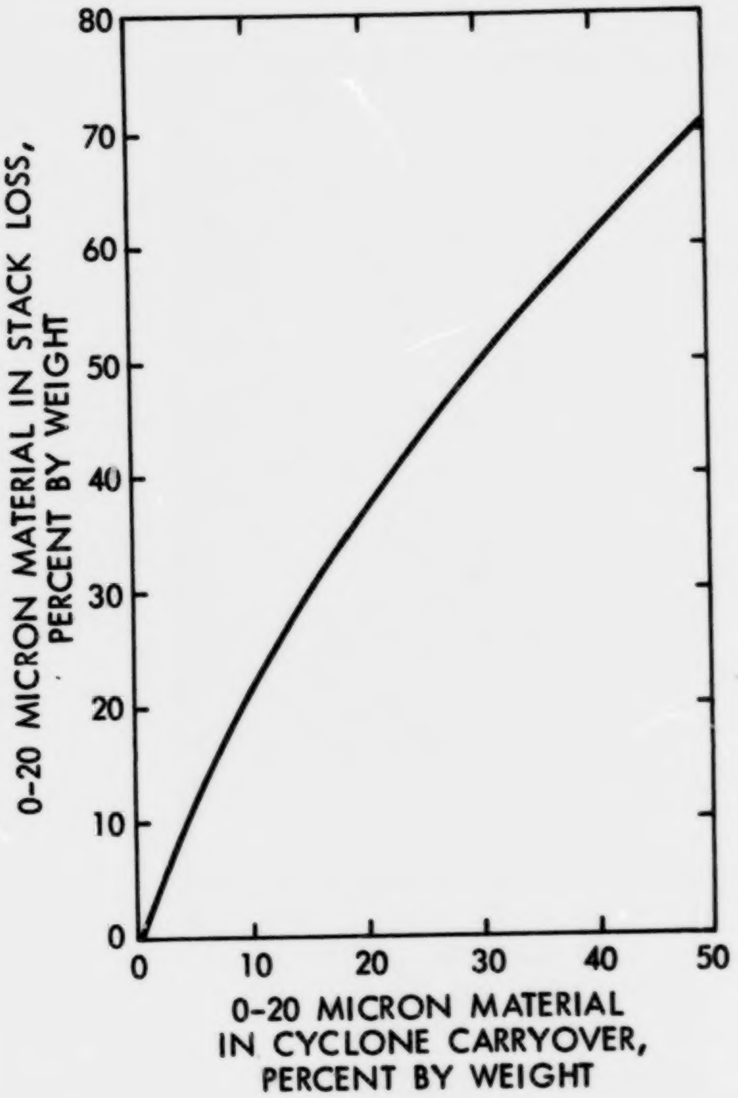


Figure 22-7 - Particle-Size Stack Loss Distribution Compared to Cyclone Carryover Particle Size[12]

Typical costs for a precipitator following an expansion turbine at 900°F are \$2/scfm, while the cost at 700°F following a CO boiler is only about \$1.50/scfm. Water injection into the effluent stream to further reduce the temperature to about 550°F will reduce the cost still more.[6] These costs compare well with the general figure for purchase costs of electrostatic precipitators given in Appendix A.

Electrostatic precipitators can continuously achieve 99% efficiencies, but in order to obtain these high efficiencies in precipitators following regenerators, it is sometimes necessary to add a small amount of ammonia to the gases entering the precipitator to lower the resistivity of the material handled by the precipitator. In designing these units, the following items are taken into consideration.[7]

1. With periods of continuous operation for FCC units and fluid coking units extending to three years or more, one should select a precipitator with more than one chamber so that part of the unit can be isolated from the gas stream for maintenance while all of the gases pass through the rest of the units.

2. The precipitator should have a large number of bus sections which are individually energized to achieve the highest power input and to minimize any decrease in efficiency if any one section is shorting out.

The dust concentration entering the precipitator depends on the type of catalyst used, the particular process and the kind of mechanical collectors used. The normal dust concentration varies between 5 and 25 grains/scf dry. It has been reported that no new catalyst recovery precipitators have been sold in recent years in this country.[11]

Changes in fuel demands have reduced the number of catalytic cracking units and consequently the number of new electrostatic precipitators needed for this service has declined. However, electrostatic precipitators are still being used on some existing catalytic crackers and at least three units were sold for this purpose during the 1966-1967 period.[16] A summary of performance data for precipitators in fluid catalytic cracking applications during the period 1951-1962 is shown in Table 22-4.[17]

TABLE 22-4

A SUMMARY OF PERFORMANCE DATA* OF PRECIPITATORS IN FLUID CATALYTIC CRACKING APPLICATION (1951-1962)[17]

Parameter	Maximum	Minimum	Average
Gas Volume, 1000's acfm/Pptr.	254	6	152.6
Gas Temperature, °F.	850	450	610
Inlet Loading, lb/hr	2,800	77	1,444
Coll. Efficiency, %	99.7	80	95

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* These data based on seven installations.

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CHAPTER 23

ACID MANUFACTURE

23.1 INTRODUCTION

Acid manufacturing processes include those for sulfuric, phosphoric, nitric, and hydrochloric. Only sulfuric and phosphoric acid manufacture discharges significant particulate emissions.

More sulfuric acid is produced in the United States than any other chemical. The chamber process for the production of sulfuric acid has been largely displaced by the contact process. About 97% of current output is from contact plants. Elemental sulfur accounts for about 75% of all raw materials consumed in sulfuric acid production. Most of the remaining new acid comes from pyrites or other iron sulfides, smelter gas, hydrogen sulfide, crude sulfur, and copper, zinc, and lead ores. Increasing amounts of used sulfuric acid are recovered for reuse. Primary sources are petroleum refining, alcohol manufacture, nitric acid and chlorine drying, and detergent and other sulfonations.

The principal emissions from sulfuric acid plants are acid mists and sulfur dioxide.

Phosphoric acid is produced in two distinct processes. The wet-process acid is produced and consumed primarily in the fertilizer industry. The wet process for producing phosphoric acid is discussed in Chapter 12. The other commercial process for manufacturing phosphoric acid is the thermal process, also referred to as the furnace or phosphorus burning process. The thermal process acid is used in plasticizers, detergents, pharmaceuticals, and food grade acid.

The principal emission from the thermal process is acid mist.

Manufacturing processes, particulate emission sources, particulate emission rates, effluent characteristics, and control practices and equipment for sulfuric and phosphoric acid production are discussed in the following sections.

23.2 SULFURIC ACID MANUFACTURE

23.2.1 New Acid

All sulfuric acid is made by either the chamber or the contact process. Elemental sulfur, or any sulfur-bearing material, is a potential raw material for both these processes. The 215 contact-process establishments account for about 97% of the U. S. production. The 35 chamber-process establishments account for the balance of U. S. production.

23.2.1.1 Chamber Process: Originally the chamber process employed sulfur dioxide gas produced from sulfur, but roaster gas or smelter gas was substituted later. The process employs the following principal units in addition to the combustion chamber or SO_2 source (see Figure 23-1):

1. The Glover tower which receives the hot burner gas. It is fed at the top with the nitrous vitriol from the Gay-Lussac tower, and with 52° Bé (65%) acid from the chambers. The functions of the Glover Tower are to denitrify the Gay-Lussac acid, thus reducing niter requirements to a small makeup for process loss; to evaporate water from the chamber acid, thus concentrating it to about 60° Bé (78%); cooling the gas to the point at which it can be safely introduced into the lead chambers; and supplying water vapor, equivalent to about one-third of the water requirement of the set (when producing acid of 52° Bé).

2. A series of large lead chambers, usually comprising from three to as many as ten, in which the reactions between sulfur dioxide, oxygen from the air, oxides of nitrogen, and water are carried out with resultant production of chamber acid.

3. Usually two Gay-Lussac towers in series, in which the oxides of nitrogen leaving the final chamber are absorbed in sulfuric acid of about 60° Bé, and form nitrous vitriol.

4. An ejector or fan to provide the necessary flow of air through the system. The ejector may be located in the exit stack from the Gay-Lussac tower; a fan is usually placed between the final chamber and Gay-Lussac tower. Occasionally the fan is placed between the Glover tower and first chamber, although this location is not preferred because of its high temperature.

23.2.1.2 Contact Process: The contact process was first discovered in 1831 by Phillips, an Englishman, whose patent included the essential features of the modern contact process, namely, the passing of a mixture of sulfur dioxide over a catalyst followed by absorption of the sulfur trioxide in water.

Figure 23-2 illustrates a typical flow diagram for this process. The flow diagram can be divided into the following sequences:2/

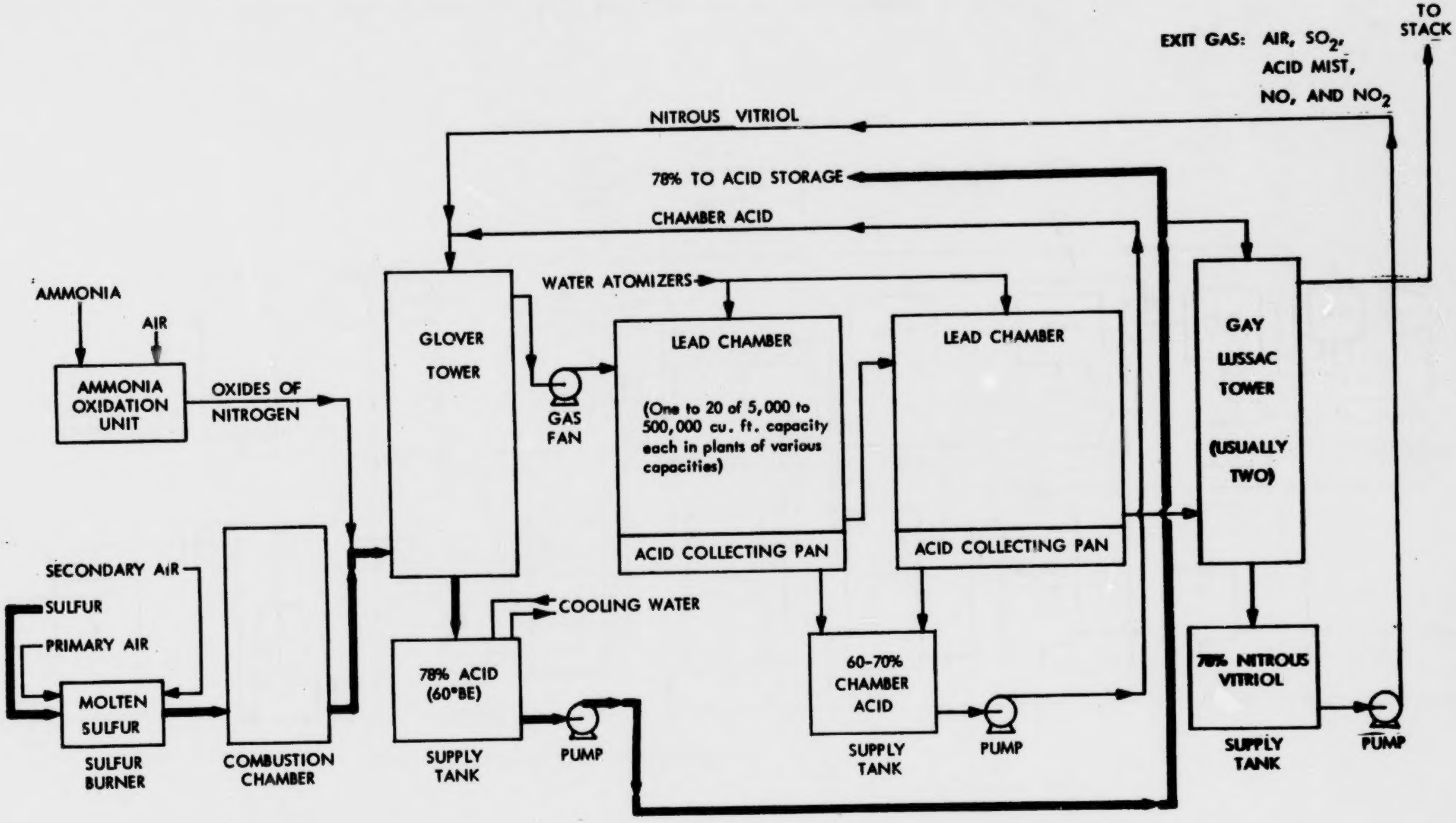
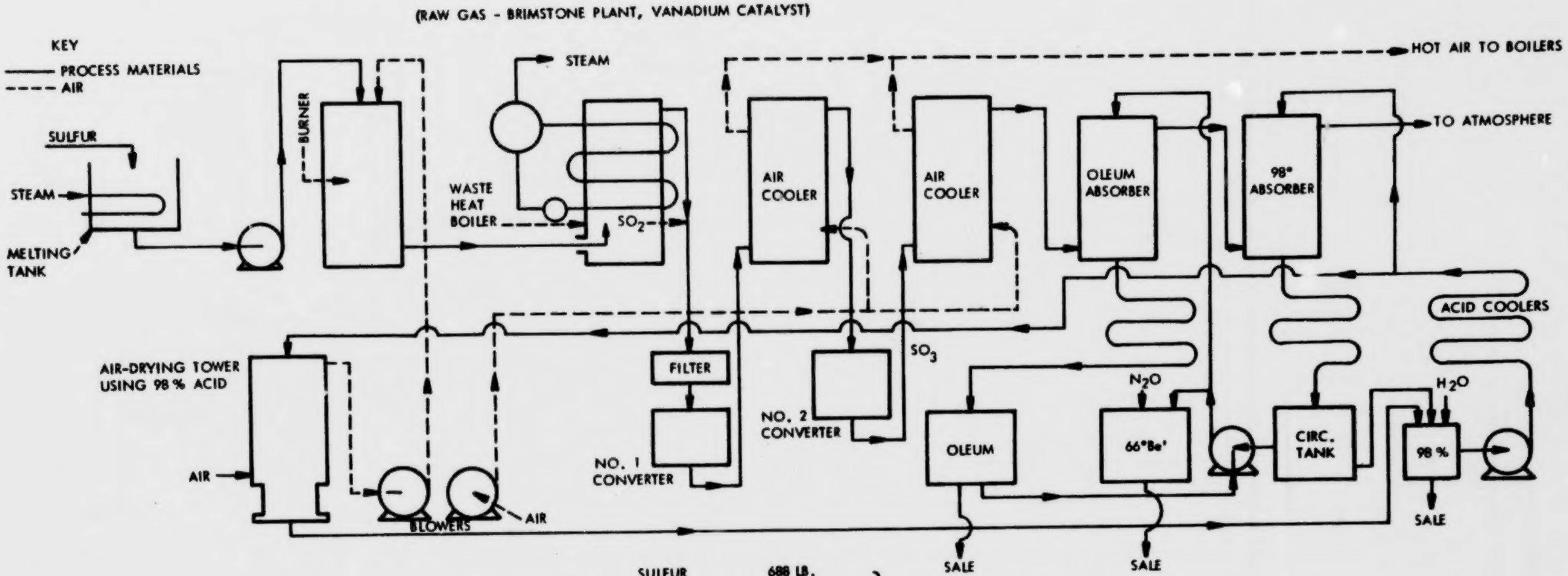


Figure 23-1 - Simplified Flow Diagram of Typical Lead-Chamber Process for Sulfuric Acid Manufacture (Based on Use of Elemental Sulfur as the Raw Material)[1]


(RAW GAS - BRIMSTONE PLANT, VANADIUM CATALYST)

SULFUR	688 LB.	PER TON 100 % ACID IN A PLANT OF 50 TONS PER DAY CAPACITY
WATER	4,000 GAL.	
ELECTRICITY	5 KW.HR.	
DIRECT LABOR	0.64 MAN-HR	
STEAM*	200 LB.	

* WASTE HEAT BOILER WILL FURNISH UP TO 2,000 LB. STEAM

Figure 23-2 - Sulfuric Acid Manufacture by the Contact Process[2/]

1. Transportation of sulfur or sulfides to plant
2. Melting of sulfur
3. Pumping and atomizing of melted sulfur
4. Burning of sulfur
5. Drying of combustion air
6. Recovery of heat from or cooling of hot SO_2 gas
7. Purification of SO_2 gas
8. Oxidation of SO_2 to SO_3 in converters
9. Temperature control to secure good yields of SO_3
10. Absorption of SO_3 in strong acid
11. Cooling of acid from absorbers
12. Pumping acid over absorption towers

23.2.2 Regenerated Acid

Substantial quantities of "fresh clean acid" are made by regeneration or decomposition of spent acid from petroleum refineries or other chemical processes. Sulfuric acid may be concentrated to around 66° Bé by heat. Any further fortification is usually done by the addition of oleum or sulfur trioxide. Two types of equipment for concentrating dilute acid operate under a vacuum while the third operates at atmospheric pressure using air-blown combustion gases.

A typical air-blown concentrator is shown in Figure 23-3. The burner supplies the hot gases at about 1100°F by the combustion of oil or fuel gas. These hot combustion gases are blown countercurrent to the sulfuric acid in two compartments in the concentrating drum and remove water as they bubble up through the acid. The off-gases at 440 to 475°F from the first compartment of the drum pass to the second compartment along with a portion of the hot gases from the combustion furnace. They leave at 340 to 360°F to enter a gas-cooling drum where they are cooled to 230 to 260°F in raising the dilute acid to its boiling point. Since some sulfuric acid is entrained as a mist, the hot gases then pass through a Cottrell-type precipitator for the acid mist before discharge to the atmosphere. A Venturi scrubber with cyclone separator is also giving competitive results

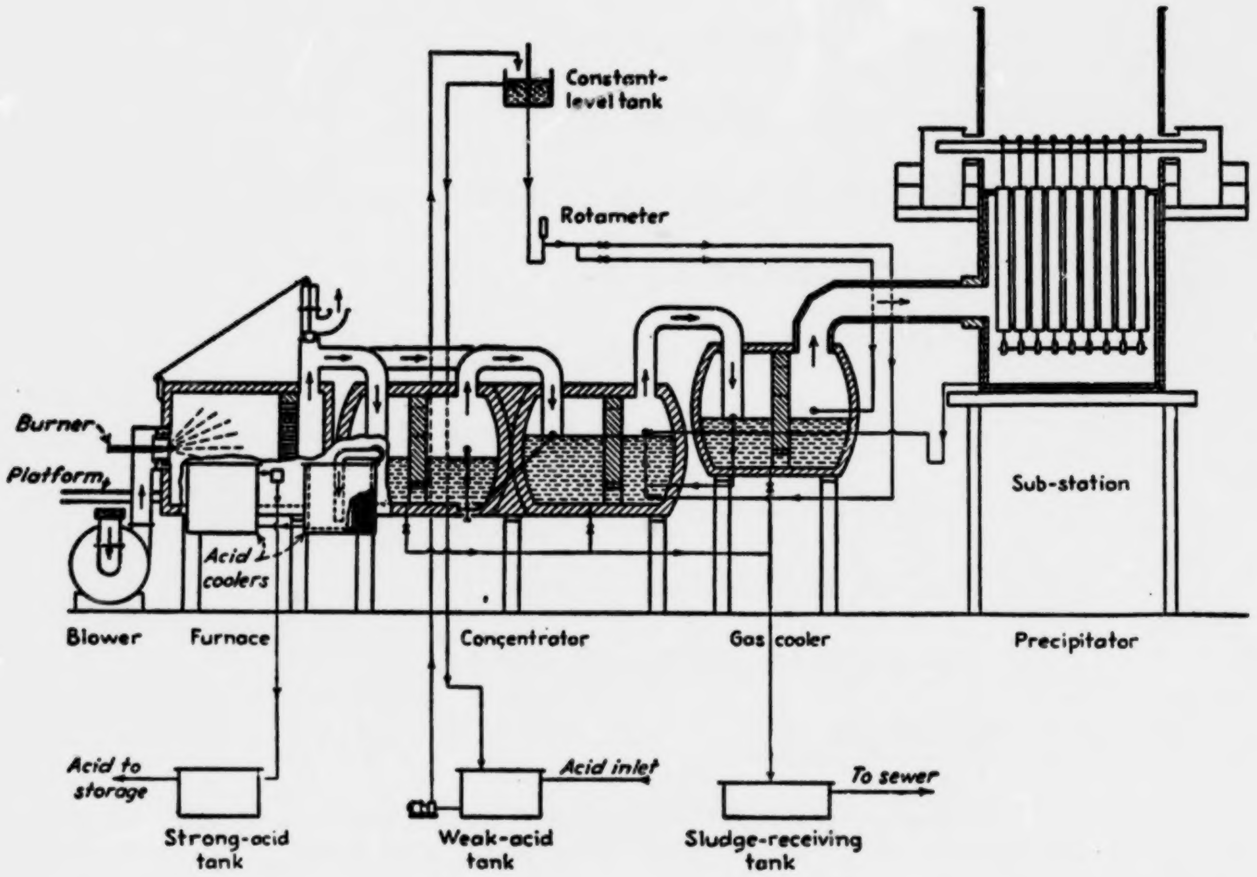


Figure 23-3 - Sulfuric Acid Concentrator, Drum Type.[2]

in removing acid mist by washing with feed acid. This procedure will give an acid with a final concentration of 93% or slightly higher. The hot gases also burn out any impurities that may be in a spent acid being concentrated.[2]

There are five types of vacuum concentrators which will permit concentration of practically any acid, though clean acid is preferred to avoid fouling of interfaces. The necessary heat is supplied by high-pressure steam or Dow-therm. The Type E concentrator is the largest and desirable for high concentrations. For the latter reason, this type of concentrator is employed on relatively clean acids such as some nitration acids. It is a vertical steel shell lined first with lead followed by acid-proof brick. The metallic tubular heaters inserted through the vertical wall of the vessel are constructed of Duriron or Hastelloy D. Usually there are two or more units in series. The Type D concentrator is a small batch unit with vertical tubes in a vertical cylindrical tank, suitable for acid concentrations up to 93%. The Type C unit consists of many small compartments with individual heaters in series through which the acid to be concentrated flows continuously. The Type B concentrator, a batch unit, is a vertical tank with lead heating coils used mainly for acid concentration up to 80%. The Type A unit can be operated continuously or batchwise. This special corrosion-resistant, high-circulation evaporator is used quite often for the removal of sodium sulfate from the waste acid liquor being discharged from the viscose spinning bath, as well as reconcentrating the remaining acid values. Types C and E have a practical concentration limit of 95% acid.[2]

23.3 EMISSION RATES

23.3.1 New Acid

23.2.1.1 Chamber Plants: The primary source of emissions in the chamber process is the final Gay-Lussac tower. Emissions include nitrogen oxides, sulfur dioxide, and sulfuric-acid mist and spray.

Concentrations of total nitrogen oxides in these exit gases range from about 0.1 to 0.2 vol. %. Sulfur dioxide concentrations occur in the same range. About 50 to 60% of the total nitrogen oxides is nitrogen dioxide, which characterizes the exit gas by a reddish-brown color.

Combined sulfuric acid mist and spray in the exit gas varies from 5 to 50 mg/scf. The sulfuric acid mist contains about 10% dissolved nitrogen oxides.

23.3.1.2 Contact Plants: The major source of emissions from contact sulfuric acid plants is the exit gas from the absorber. This gas contains unreacted sulfur dioxide, sulfuric acid spray and mist, and unabsorbed sulfur trioxide. Trace amounts of nitrogen oxides may also be present under some conditions, e.g., use of a raw material feed containing nitrogen compounds. Acid mist emissions prior to any control equipment average between 5-10 mg/scf for sulfur-burning plants producing no oleum and about 15-30 mg/scf for those plants producing oleum.

Unconverted sulfur dioxide gas, which is colorless, passes through the absorption system and is discharged to the atmosphere. The quantity of this gas emitted is a direct function of the degree of conversion of sulfur dioxide to sulfur trioxide and may vary from 0.1 to 0.5% by volume of the stack gases. During startup or during some emergency shutdowns, higher concentrations will occur.

Unabsorbed sulfur trioxide usually constitutes a small part of the absorber exit gas. When discharged to the atmosphere it is hydrated and forms a visible white plume of acid mist. Although the concentration of unabsorbed sulfur trioxide can vary appreciably, from 0.5 to 48 mg/scf of gas, it is usually closer to the lower figure and is a small part of the total acid mist emission.1/ Other emission sources for this type of sulfuric acid plant include:

1. acid concentrators
2. tank car and drum-loading
3. storage tank vents
4. storage piles

Table 23-1 summarizes particulate emission rates for chamber and contact plants. Chamber plants currently emit about 2,000 tons/yr, while contact plants emit about 4,000 tons/year.

23.3.2 Regenerated Acid

The concentration of sulfuric acid in vacuum-type concentrators does not produce atmospheric pollution problems.

The effluent gases from air-blown concentrators contain sulfuric acid mist and sulfur dioxide resulting from the decomposition of sulfuric acid by carbonaceous materials in spent acid.13/ Spent gases go to a scrubbing tower, or more generally to an electrostatic precipitator, for the removal of sulfuric acid mist. Limited data in the open literature indicate that fume emission rates are a function of plant operating and maintenance practices.14/

Emission rates for acid regenerators are summarized in Table 23-1. Emissions are estimated at 8,000 tons/year.

TABLE 23-1

PARTICULATE EMISSIONS
MINERAL ACIDS

Source	Quantity of Material	Emission Factor	Efficiency of Control C_c	Application of Control C_t	Net Control $C_c \cdot C_t$	Emissions ton/yr
I. Sulfuric Acid						
A. Processing Units	28,000,000 tons of H_2SO_4					
1. Gay-Lussac tower (chamber process)	1,000,000 tons of H_2SO_4	5 lb/ton H_2SO_4	0.0	0.0	0.0	2,000
2. Absorber (contact process)	27,000,000 tons of H_2SO_4	2 lb/ton H_2SO_4	0.95	0.90	0.85	4,000
B. Spent-Acid Concentrators						
1. Air-blown	11,200,000 tons of spent acid	30 lb/ton of spent acid	0.95	0.85	0.80	8,000
2. Vacuum						Neg.
II. Phosphoric Acid - Thermal Process	1,020,000 tons of P_2O_5	134 lb. particulate/ton of P_2O_5 produced	0.97	1.0	0.97	2,000
				Total from Acids		16,000

23.4 EFFLUENT CHARACTERISTICS

The chemical and physical properties of sulfuric acid plant effluents are summarized in Table 23-2. Acid mists emitted from chamber plants contain particles which are 10 wt. % less than 3 μ. Contact plants emit particulates which range from 7-95 wt. % less than 3 μ with an arithmetic mean of 64 wt. % less than 3 μ. A large percentage of smaller particles is emitted when producing oleum. Approximately 85-95 wt. % of the particles are less than 2 μ when producing oleum as compared to 30% less than 2 μ when producing 98% acid.

23.5 CONTROL PRACTICES AND EQUIPMENT FOR SULFURIC ACID PLANTS

Recovery equipment is rarely employed in chamber plants.[1] Electrostatic precipitators, packed-bed separators, mesh-type mist eliminators, ceramic filters and sonic agglomerators have been used to reduce the emission of acid spray and mist from contact acid plants.[1] Most modern plants are equipped with high-efficiency electrostatic precipitators or mesh-type eliminators in which 99% of the mist is recovered.[3]

The electrostatic precipitator and mesh-type eliminator can provide removal efficiency of up to 99.9%. However, when oleum is produced, the portion of acid mist particles smaller than 3 μ in diameter is higher. This size seriously affects the low-pressure drop mesh-type eliminators; efficiency decreases sharply, and may be less than 40%.[1]

Also, small amounts of nitrogen oxides in the inlet gas to the absorber interfere with the absorption of sulfur trioxide, and hence cause visible acid mist in the absorber exit gases.[1]

The visibility of acid mist depends more on particle size than on mist loading. Thus, a high percentage of particles 3 μ or less in the acid mist usually causes a heavy plume from the absorber stack. High-efficiency control devices do not necessarily result in an invisible plume unless there are few particles less than 3 μ and inlet mist-loading is not excessive.[1]

Acid mist composed of particles of less than 10 μ in size is visible in the absorber tail gas if present in amounts greater than 1 mg/ft^3. Larger particles deposit readily on dust and stack walls and contribute little to the opacity of the plume.[4] Internal spray catchers are installed in the top section of many absorbers to aid in the removal of large acid particles entrained in the exit gas.[1] From a plume visibility standpoint, plants producing a maximum of 99% acid (i.e., no oleum) often have clean stacks if bright, or uncontaminated, sulfur is used and the absorber is operating properly. However, plants producing oleum

TABLE 23-2

EFFLUENT CHARACTERISTICS - ACID MANUFACTURE[+]

A. Particulate (Part I)

Source	Particle Size	Solids Loading	Chemical Composition	Particle Density	Electrical Resistivity	Moisture Content	Toxicity
Sulfuric acid							
a. chamber plant	90-96 > 3	0.08-0.5	H_2SO_4	1.7			1.0, irritant
b. contact plant	7.5-95 < 3; arith. mean 63.5 < 3 (size dependent on plant type)	0.017-0.76; arith. mean - 0.2	H_2SO_4	1.7 - 1.8			1.0, irritant
c. regenerator (air-blown)		0.9-1.8	H_2SO_4				1.0, irritant
Phosphoric acid; thermal process	0.4-2.6; mass median diameter - 1.6	1.55-93 without collector 0.001-0.26 with collector	H_3PO_4	1.57 - 1.68			1.0, irritant

A. Particulate (Part II)

Source	Solubility	Wettability	Hygroscopic Characteristics	Flammability or Explosive Limits	Handling Characteristics	Optical Properties	Odor
Sulfuric acid							
a. chamber plant	s. H_2O d. alcohol				Highly corrosive		
b. contact plant	s. H_2O d. alcohol				Highly corrosive		
c. regenerator (air-blown)	s. H_2O d. alcohol				Highly corrosive		
Phosphoric acid; thermal process	s. H_2O d. alcohol				Corrosive		

B. Carrier Gas

Source	Flow Rate	Temperature	Moisture Content	Chemical Composition	Toxicity	Corrosivity	Odor	Flammability Limits	Optical Properties
Sulfuric acid									
a. chamber plant	a) 2-13 b) 100-160	105	5-25	NO_x - 0.1-0.2 NO_2 - 0.05-0.12 SO_2 - 0.1-0.2 O_2 - 8-17 N_2 - balance	SO_2 5; irritant	Corrosive			Opacity - medium
b. contact plant	a) 5-62 b) 72-130	76-212		SO_2 - 0.13-0.54 arith. mean - 0.26; air - balance	SO_2 5; irritant	Corrosive			Opacity - none to dense
c. regenerator (air-blown)	a) 58.5 (one plant)	330							
Phosphoric acid; thermal process	a) 3.4-30.2 b) 35-160	136-201	10-60	H_2O, NO_x, Air-balance		Corrosive			0-100% opacity

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[+] See Coding Key, Table 5-1, Chapter 5, page 45, for units for individual effluent properties.

generally need either high-efficiency electrostatic precipitators or high-efficiency mist collectors. Table 23-3 presents a summary of "feasible systems" for acid mist control.[16]

The concentrating of sulfuric acid in air-blown concentrators can also result in emissions of sulfuric acid mist and spray. These emissions can be controlled by the use of electrostatic precipitators, Venturi scrubbers or fiber-mesh eliminators.[1]

TABLE 23-3

FEASIBLE SYSTEMS FOR ACID MIST CONTROL[16]

	Efficiency > 3 μ (%)	Efficiency < 3 μ (%)	Emission Level 99% Acid Plants[a] (mg/scf)	Emission Level Oleum Plants[a] (mg/scf)
1. Dual Mist Pads	99+	15-30	2	to 5
2. Tubular-Type Mist Eliminator	100	95-99+	0.1	0.1
3. Panel-Type Mist Eliminator	100	90-98	0.5	0.5
4. Electrostatic Precipitator	99	Near 100	0.1	0.5
5. Venturi Scrubber	98	Low	3	Ineffective with 3 μ mist

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[a] Based upon manufacturers' generally expected results.

One company studied the removal of sulfuric acid mist, on pilot plant scale, by low-pressure water sprays, high-pressure water sprays, and bag filters, and by decomposition with heat. This study led to installation of a high-pressure water spray system on a facility concentrating 700 tons/day of acid from 70% to 95% in air-blown concentrators. The unit was designed to spray 500 gpm of water at 540 psi spray nozzle pressure. Fuel gas burners were installed in the base of the acid fume stack to raise the temperature of the effluent gases from 140°F to 212°F.[5]

23.5.1 Control Equipment

23.5.1.1 **Wire-Mesh Mist Eliminators:** This control device has the lowest first cost for effective removal of particles larger than about 3 μ in diameter. However, corrosion possibilities may require frequent replacement of this type of control device; therefore costs will rise and these increased costs must be considered.[4]

The wire mesh eliminator is commonly constructed with two beds in series and operates with pressure drops of 1-3 in. of water.[1] Typical gas velocities for these units range from 11 to 18 ft/sec.[4]

23.5.1.2 **Glass-Fiber Mist Eliminators:** The high-efficiency glass-fiber mist eliminator is capable of operating with collection efficiencies of over 99%. Pressure drop is usually 5-10 in. w.g. The glass-fiber mist eliminator is also capable of maintaining high efficiency at varying tail-gas flow rates.[1]

A recent development in this area involves the use of a teflon fiber mist pad. This device is reported to be 98% efficient even when inlet loading is as low as 10 mg/ft^3.[6]

23.5.1.3 **Electrostatic Precipitators:** Electrostatic precipitators are highly efficient regardless of size of the acid-mist particles. They operate with pressure drops less than 1 in. w.g.

Electrostatic precipitators may be either wet or dry type. The dry type, which is suitable only for concentrated acid, is much less expensive but more susceptible to corrosion. Wet-type precipitators are suitable for use only with dilute acid, and this necessitates prior humidification of stack gases. This also permits removal of SO_3 by converting it to acid mist. However, the humidification step appreciably increases the cost of a wet-type installation.[1]

The lead constructed electrostatic precipitator, for low-strength acid mist emissions, is used throughout the industry as the primary means of emission control. The use of mild steel electrostatic precipitators for oleum stack cleanup has been reported as successful with considerable savings in cost.7/

23.5.1.4 Ceramic Filters: This German device is reported to operate with high efficiency at constant tail-gas flow rates. It has not been accepted in the U. S. because of high maintenance costs and inflexibility in handling varying gas volumes.1/

23.5.1.5 Venturi Scrubbers: Venturi scrubbers are capable of high efficiency but at the expense of high pressure drop. They have not been used on contact acid plants, but have been used on sulfuric-acid concentrators to give outlet (i.e., grain loading) mist loadings of 0.5-3.0 mg/ft^3.1/

23.5.1.6 Packed Bed Separators: These low-efficiency devices were used in the past, but none are known to be operating today.1/

23.6 PHOSPHORIC ACID MANUFACTURE

Phosphoric acid is manufactured by two processes: 1) the thermal process and (2) the wet process. The thermal process proceeds by burning elemental phosphorous to the pentoxide, followed by a hydration step. The wet-acid process involves treatment of phosphate rock with sulfuric acid. About 75% of the phosphoric acid produced comes from the wet acid process, and about 92% of the wet-process phosphoric acid goes into fertilizer production. About 19% of the thermal process phosphoric acid goes into fertilizer production, with the rest of the acid from both processes going into the production of other industrial chemicals.

23.6.1 Thermal Process

In the manufacture of phosphoric acid from elemental phosphorus, three steps are involved: (1) burning of the phosphorus, (2) hydration of the resulting phosphorus pentoxide, and (3) collection of the mists formed. A schematic diagram of the thermal process is shown in Figure 23-4. In most plants the elemental phosphorus is burned as a liquid. The problem of building a burner for liquid phosphorus is complicated by the fact that red phosphorus tends to form at elevated temperatures and can plug the burner completely or give rise to color in the resulting acid. The build-up of red phosphorus is usually avoided by a design in which rapid atomization of the phosphorus takes place.

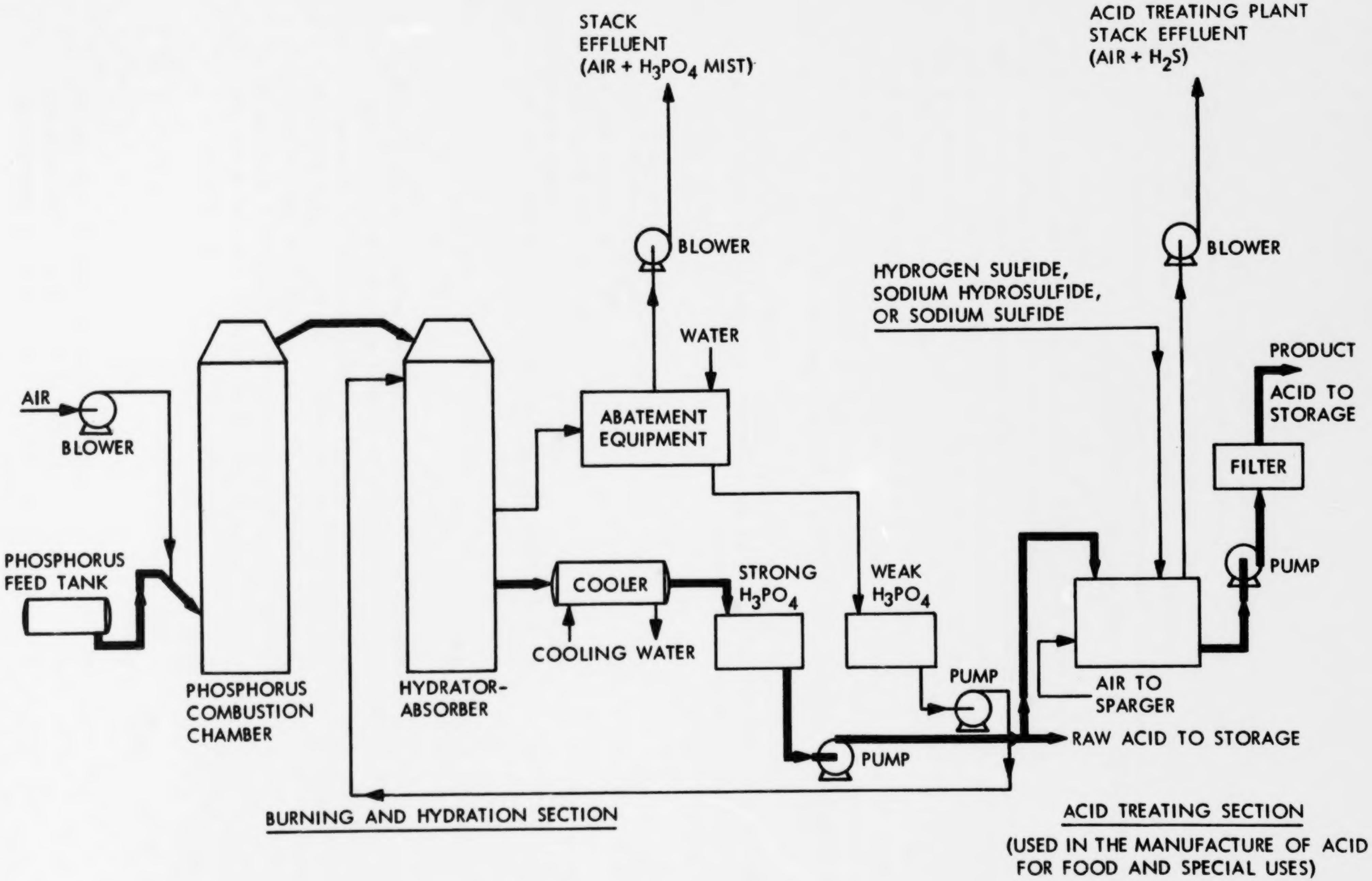

STACK EFFLUENT (AIR + H_3PO_4 MIST)
ACID TREATING PLANT STACK EFFLUENT (AIR + H_2S)
BLOWER
BLOWER
HYDROGEN SULFIDE, SODIUM HYDROSULFIDE, OR SODIUM SULFIDE
WATER
PRODUCT
ACID TO STORAGE
AIR
BLOWER
ABATEMENT EQUIPMENT
FILTER
PHOSPHORUS FEED TANK
COOLER
STRONG H_3PO_4
WEAK H_3PO_4
PUMP
COOLING WATER
PHOSPHORUS COMBUSTION CHAMBER
HYDRATOR-ABSORBER
PUMP
AIR TO SPARGER
RAW ACID TO STORAGE
PUMP
BURNING AND HYDRATION SECTION
ACID TREATING SECTION
(USED IN THE MANUFACTURE OF ACID FOR FOOD AND SPECIAL USES)

Figure 23-4 - Flow Diagram for Typical Thermal-Process Phosphoric Acid Plant[9]

Phosphorus is transferred from the liquid-phosphorus feed tank to the burner tower by a pump or by liquid displacement at feed rates that range from 1 to 5 gal/min. At the burner the phosphorus is mixed with air and is oxidized at temperatures of 3000° to 5000°F in the combustion chamber.[8] The resulting mixture of phosphorus pentoxide vapor and excess air passes from the combustion tower and into the hydrator.

Although many plants have refractory or graphite-lined combustion towers, a few new burning towers are constructed of water-jacketed stainless steel. In stainless steel towers weak phosphoric acid introduced into the combustion tower flows down the walls to remove excess heat. The phosphorus pentoxide vapors from the combustion tower are contacted with weak and product acid to hydrate the oxide to phosphoric acid and to absorb acid mist. These steps may be accomplished in one unit, but many plants use separate absorbing towers. In some new designs the acid sprayed into the hydrator is cooled prior to recycle. This spraying permits use of a smaller quantity of acid and allows the production of higher strength acid.

Some product acid is drained from the bottom of the hydrator-absorber. Gases containing acid mist leave the hydrator-absorber and enter air pollution abatement equipment.

The yields from thermal production of phosphoric acid are exceptionally high. In efficient plants about 99.9% of the phosphorus burned is recovered as acid. The loss of acid through leaks and discharges to sewers is usually negligible. Losses of phosphoric acid to the atmosphere represent direct product loss; therefore, efficient collection devices are normally installed in the gas stream before the gas is discharged from the plant.

23.6.2 The Wet Process

The oldest and still the most economical method for making crude phosphoric acid is to treat phosphate rock with sulfuric acid, thereby precipitating calcium sulfate and releasing phosphoric acid. However, to make phosphoric acid for any application other than fertilizers, it is necessary to purify the crude material obtained by the wet process. This purification may range from the removal of coloring materials such as iron and vanadium to the preparation of a food-grade acid. The wet-acid process for the manufacture of phosphoric acid is described in the chapter on Fertilizer Manufacturing.

23.6.3 Emission Rates

The principal atmospheric emission from the manufacture of phosphoric acid by the thermal process is acid mist in the absorber discharge gas. In the normal operation of the plants the hydration of phosphorus pentoxide (P_4O_{10}) creates phosphoric acid mist. Acid mist loadings within the process can be quite high. Loadings as high as 6,000 mg/dry scf of stack gas have been reported. It is not uncommon for as much as half of the total phosphorus pentoxide to be present as liquid phosphoric acid particles suspended in the gas stream. Economical operation of the process depends on agglomeration of the acid mist particles and subsequent separation from the gas stream. For this reason all plants are equipped with some type of emission control equipment.

Thermal-process acid manufacture employs high-temperature combustion that is normally conducive to the formation of nitrogen oxides. Many factors such as flame temperature, residence time, and quantity of excess air affect the amount of nitrogen oxides formed.

No serious problems are encountered in the startup or shutdown of a thermal phosphoric acid manufacturing unit that affect losses from the final collector. Maintenance of proper liquid flows and pressure differentials on the absorbers and collectors allows little or no increase in acid mist discharged to the atmosphere during either startup or shutdown.

Maintenance is not usually considered to be a major problem. Sprays, fans, mist eliminators, and other equipment obviously must be maintained in good operating condition. If a continuous-emission monitor is used on the collector exhaust, problems with the abatement equipment will be apparent to the operator quickly. Operators are normally concerned with keeping losses at a minimum because any loss is a direct loss of product.

Table 23-1 summarizes particulate emission rates for phosphoric manufacture by the thermal process. Emissions currently total about 2,000 tons/year.

23.6.4 Effluent Characteristics

The chemical and physical properties of thermal phosphoric acid plant effluents are summarized in Table 23-2. The mass median diameter of the emitted particulates is 1.6 µ.

Data on the wet process are presented in the chapter on Fertilizer Manufacturing.

23.6.5 Control Practices and Equipment

Venturi scrubbers, packed scrubbers, glass-fiber mist eliminators, wire-mesh mist eliminators, and electrostatic precipitators are used as abatement equipment at phosphoric acid plants.[9]

Operating practices have little effect on emissions of acid mist. The acid mists escaping collection are extremely hygroscopic so that visible emissions are pronounced unless high collection efficiencies are achieved.[3] The stack gases leaving phosphoric acid plants can be made completely invisible when the mist loading is reduced to 0.02 mg. of P_2O_5/scf of stack gas, the concentration of the mist in the collector is at least 75% phosphoric acid, and the stack gas temperature is above 176°F.[9]

23.6.5.1 Scrubbers: Packed and open tower scrubbers have been used widely to collect phosphoric acid mist. An important factor in efficient collection is gas velocity. The effect of gas velocity on efficiency in a pilot plant packed tower is given in Figure 23-5.[9]

Scrubbing is inexpensive and simple, but high collection efficiency is not usually obtained. Some plants have improved efficiency by installing wire-mesh mist eliminators after the scrubber.

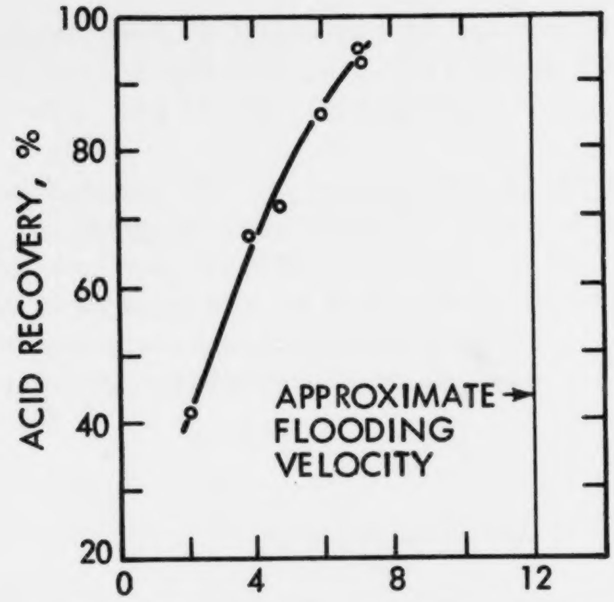
23.6.5.2 Venturi Scrubbers: Venturi scrubbers are capable of operating at high collection efficiencies on phosphoric acid mist.[9] The extremely small size of the mist particles usually requires pressure differentials in excess of 40 in. of water. Figure 23-6[17] illustrates the effect of particle size on collection efficiency. It is reported that Venturi scrubbers can reduce emissions to 0.10 mg/scf.[10]

Venturi scrubbers are not used solely for abatement as they can actually hydrate part of the phosphorus pentoxide vapor, agglomerate the mist particles and cool the stack gases; they may then be followed by cyclonic separators. This combination can recover up to 99.9% of the acid mist at pressure drops of 35-60 in. w.g.

23.6.5.3 Cyclonic Separators: Cyclonic-type collectors are used in some plants but because of the small particle size of the emitted acid mist, other devices usually supplement these collectors. Supplemental collectors are typically wire-mesh mist eliminator pads of low pressure differential.

23.6.5.4 Glass-Fiber Mist Eliminators: Glass-fiber mist eliminators are capable of high collection efficiency in removing phosphoric acid mist from absorber effluent gas streams. When the mist eliminators are operating at a superficial vapor velocity of less than 1 fps and at pressure differentials of about 20 in. of water, collection efficiencies of 99.9% are attainable.[11] It is reported that these units can reduce emissions to as low as 0.10 mg/scf.[10]

23.6.5.5 High-Energy Wire-Mesh Contactors: This is a recently developed device which is reported to give collection efficiencies that exceed 99.9% at pressure differentials ranging from 35 to 41 in. of water.[12]



Tower Packing: 18 Ft. of 1-In. Carbon Raschig Rings
Acid Concentrations: 81-87% H_3PO_4
Inlet Gas Temperature: 440° - 550°F
P_2O_3 Content of Gas: 2.0 - 2.5 Lb/1,000 Ft^3

Figure 23-5 - Effect of Gas Velocity on Phosphoric Acid Recovery in Pilot-Plant Packed Tower[9]

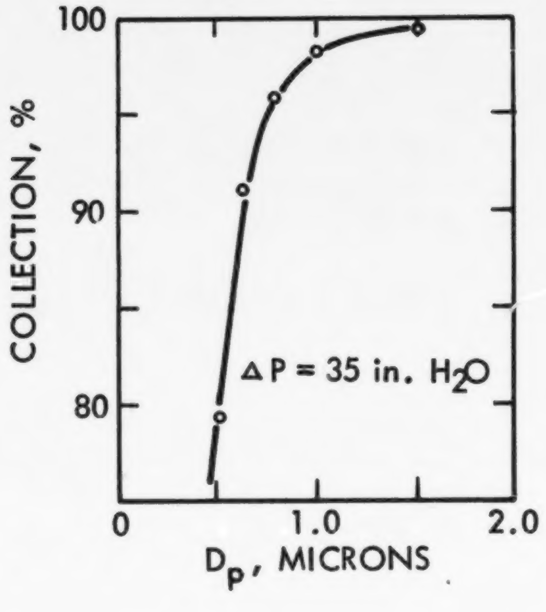


Figure 23-6 - Collection Efficiency of Venturi Scrubber as a Function of Particle Size for Phosphoric Acid Mist[17]

The unit has the advantage of operating at relatively high superficial vapor velocities of 20 to 30 fps which results in low capital cost.[9] Installed cost is reported to be approximately $1.50 per acfm of stack gas.[12]

23.6.5.6 Electrostatic Precipitators: Phosphorus pentoxide losses from electrostatic precipitators are affected only slightly by rate of gas flow or by temperature, as long as design conditions are not exceeded. Acid mist losses are affected by cleanliness of the equipment and the electrical conditions employed. Precipitators operate at a pressure drop of about 0.5 in. of water. Table 23-4 shows electrostatic precipitator data for six installations.[9]

TABLE 23-4

OPERATING CHARACTERISTICS OF PHOSPHORIC ACID MIST ELECTROSTATIC PRECIPITATORS[9]

Installation	Gas Flow Rate[a] (scfm)	Inlet Temperature (°F)	Inlet Mist Conc. As Noted	Outlet Mist Conc. As Noted	Collector Efficiency (%)	Rated Capacity (%)
1	3,160	227	7.45[b]	0.08[b]	98.9	147
2	14,100	292	14.21[b]	0.415[b]	97.1	119
3	3,540	173	3468[c]	0.10[c]	99.9+	75
4	3,900	192	3650[c]	0.16[c]	99.9+	114
5	3,570	195	4060[c]	0.24[c]	99.9+	104
6	7,300	234	278[d]	10.43[d]	96.3	101

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[a] 29.92 in. Hg and 32°F.

[b] Grains/scf dry gas as P_2O_5.

[c] Milligrams 80% H_3PO_4/cf dry gas at temperature.

[d] Milligrams mist/scf dry gas at 60°F as P_2O_5.

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CHAPTER 24

INCINERATION

24.1 INTRODUCTION

Incineration is not strictly an industrial process. However, incineration is used in many industries for waste disposal, and this combustion process is a significant source of particulate pollution on a nationwide basis. This chapter on incineration is included for the sake of completeness.

Incineration is a combustion process, and like all combustion processes incineration will cause air pollution unless carefully controlled. In comparison with the potential air pollution emissions from electric generating plants and chemical/manufacturing industries, incineration appears as a relatively unimportant source. This perspective is deceiving, however, since incinerators are often located in residential areas and are often equipped with inadequate or no control equipment.[1]

The air pollutants arising from incineration of solid wastes fall into three categories: (1) mineral particulate; (2) combustible solids and gases; and (3) noncombustible gases. Emissions are dependent upon incinerator design and operating factors, refuse composition, refuse-charging rate, and combustion efficiency.

To facilitate discussion, incinerators will be grouped into three types: (1) municipal; (2) commercial; and (3) apartment house. Emission sources, emission rates, chemical and physical properties of effluents, control practices, and control equipment are discussed for each incinerator group in the following sections.

24.2 MUNICIPAL INCINERATION

Municipal incineration is a useful, effective method of solid waste disposal. However, poor design, management, or operator judgment, may culminate in ineffective, costly operations that in turn result in air pollution, odor, and other problems.

The basic elements of a municipal incinerator are the storage pit, where refuse is deposited from collection trucks; the furnace, where the refuse is ignited and most of the combustion takes place; the secondary combustion chamber where additional combustion of volatile gases and particulate matter occurs; a settling chamber; and the stack or chimney. In addition, a plant will usually have scales to weigh incoming vehicles, a means of transferring refuse from the storage pit to the furnace and a residue removal system.[2]

The general types of incinerators for municipal use can be divided into two classes: (1) batch, or intermittant feed incinerators, where refuse is admitted into the furnace at intervals; and (2) continuous-feed furnaces, wherein refuse is fed into the furnace in a steady flow. The former furnaces generally burn down each charge on the grates before admitting another charge. To some extent batch feed furnaces may operate in an approximately continuous fashion by admitting increments of refuse at close intervals. Continuous-feed furnaces utilize one or more forms of mechanical grates. Residue is usually dumped and removed continuously. Some types of grates convey a tumbling action to the refuse to provide more rapid and complete burning and to promote ash removal.[2] Design details of various units are presented in References 2-4.

24.2.1 Emission Sources and Rates

Particulates from refuse incineration originate from dust raised in the refuse dumping and handling processes, smoke discharged through semiporous furnace walls and stoking doors, and entrained dust in the gases discharged from the furnaces. The first two are minor sources and are extraneous to the burning process.

The mass emission rate for particulates from the combustion process is a function of many variables: (1) undergrate air velocity; (2) refuse ash content; (3) burning rate or combustion quality; (4) grate agitation in a continuous feed incinerator; (5) size, method, and frequency of feeding for batch units; and (6) combustion chamber design. Items 1 and 2 are the major factors.

A systematic study by the Public Health Service of the effects of underfire air, secondary air, excess air, charging rate, stoking interval, and fuel moisture content on particulate emission rates from an experimental incinerator led to the conclusion that the velocity of the underfire air was the dominant factor influencing the emission rate.[1,5] Subsequent field evaluation of emission rates from municipal units indicated that the effect of underfire air rate was less pronounced than that observed in the experimental unit. For the two municipal incinerators tested, the effect was small for undergrate velocities below 35 to 40 scfm/sq ft of grate area; but significant above that rate.[1,6] Test results reported by other investigators parallel the effects noted in the experimental unit.[7] Figure 24-1 illustrates a comparison of the data on the experimental incinerator and the field tests. The spread in the data is not surprising in view of probable differences in refuse composition, furnace size, and other factors.[1]

The influence of refuse ash content on emission rates was also studied in an experimental incinerator.[5] In one series of laboratory tests the level of underfire combustion air was varied from 3 to 60 scfm/sq ft of grate area, and the resulting particulate emissions ranged from 1.6 to 8.6 lb/ton of combustible material burned. The fuel was a mixture of newspaper, cardboard, and wood chips. When a high ash content paper was substituted for the newspaper portion, a similar series of tests produced even higher particulate emissions, ranging from 3.2 to 35 lb/ton of combustible material for the same range of underfire air flow rates.

In a second laboratory study which was made to evaluate emissions produced by burning a high volatile material composed of asphalt felt roofing and newspaper, tests were made under conditions in which the level of underfire air was varied while all other variables were held constant. The resulting particulate emissions increased from 5.3 to 19.8 lb/ton of fuel burned. In this case, the level of underfire air ranged from 6 to 34 scfm/sq ft of grate area on tests made at 100% excess combustion air. With 200% excess air, particulate emissions increased from 11.2 to 47.2 lb/ton of material burned when underfire air was varied from 8.5 to 50 scfm/sq ft of grate area.

The dependence of particulate emission rate on ash content of the refuse has also been noted by German investigators.[1] These findings show that the ash content of the refuse is a major factor in determining emission rates.

Reference 1 contains a discussion of the influence of secondary variables on emission rates.

24.2.1.1 Summary of Emission Rates: Particulate emissions from municipal incineration have been estimated at 100,000 tons/year.[1] Table 24-1 gives the distribution of the various types of emissions from municipal incinerators.

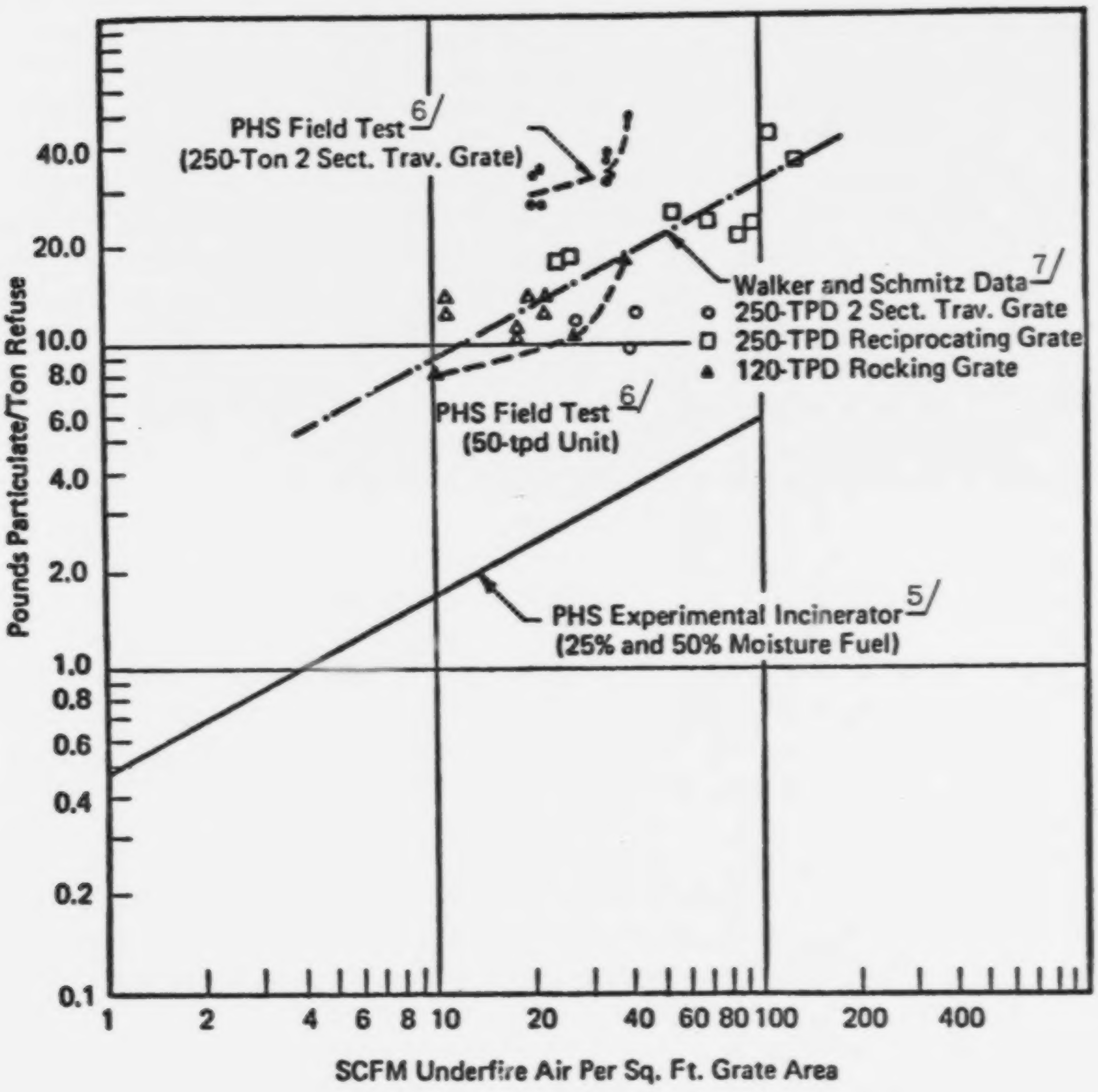

Figure 24-1 - Effect of Underfire Air Rate on Furnace Emission[1]

TABLE 24-1

ESTIMATED MUNICIPAL INCINERATOR EMISSIONS[1]
(thousands of tons/year)

Pollutant	1968 Emissions Estimate	
	Furnace	Stack
Mineral particulate	90	56
Combustible particulate	38	32
Carbon monoxide	280	280
Hydrocarbons	22	22
Sulfur dioxide	32	32
Nitrogen oxides	26	22
Hydrogen chloride	8	6
Volatile metals (lead)	0.3	0.3
Polynuclear hydrocarbons	0.01	0.005
Total	496.	450.

24.2.2 Effluent Characteristics

The physical and chemical characteristics of effluents from municipal incinerators are presented in Table 24-2. The particle size, particulate grain loading, and particulate chemical composition are highly variable and depend upon combustion efficiency, underfire airflow, incinerator design, and character of refuse. Furnaces operated in excess of design capacity generally emit a low percentage of particles smaller than 10 μ in size, while furnaces operated at less than capacity and low underfire air rates emit larger percentages of particles smaller than 10 μ in size. Electron micrographs (30-80,000 magnification) of particulate material from stacks show a very heterogeneous material. No characteristic shapes predominate. Occasional shapes could be identified such as the round spheres indicative of carbon particles, or cubes indicating magnesium oxide or the needle shape forms of zinc oxide.1/

The toxic and corrosive properties of the effluents from municipal incinerators are dependent upon the composition of the refuse burned in the unit. In addition to the fly ash and normal gaseous products of combustion (i.e., CO_2, CO, etc.), polynuclear hydrocarbons, organic acids, and aldehydes are liberated during incineration. The combustion of halogenated hydrocarbons can result in the formation of decomposition products which are corrosive and toxic, e.g., fluorides and chlorides can be emitted when aerosol cans or PVC containing materials are included in the refuse. The thermal decomposition of polyurethane-type plastics could constitute a toxic hazard because of the liberation of phosgene and/or toluene diisocyanate. The quantity and nature of these emissions are also dependent upon operating factors and incinerator design.

24.2.3 Control Practices and Equipment

A NAPCA report on municipal incineration presents average efficiency data for air pollution control systems used on municipal incinerators. Table 24-3 summarizes the efficiency data.1/ The actual application of these devices, together with investment and operating cost, is shown in Table 24-4.1/ Table 24-5 indicates the maximum efficiency of incinerator control equipment.9/

Data for installed cost and operating cost are shown in Figures 24-2 to 24-6. It should be noted that Figures 24-4 through 24-6 show annual operating costs based on operating periods of one, two and three shifts per day, respectively. An explanation of the basis for these costs is given in Section VII of Reference 1. The installed costs shown in Figure 24-3 are higher, by as much as 200% in some cases, than the general cost data given in Appendix A.

TABLE 24-2

EFFLUENT CHARACTERISTICS - INCINERATION[+]

A. Particulate (Part I)

Source	Particle Size	Solids Loading	Chemical Composition	Particle Density	Electrical Resistivity	Moisture Content	Toxicity
I. Municipal Incinerator	Coulter Counter 89.2 < 44, 30 < 69, 47 < 20, 21 < 10, 6 < 5 BAHCO Analysis 30-50 < 30, avg. 40 < 30 27-45 < 20, avg. < 36 < 20 23-38 < 10, avg. 29 < 10 13.5-23.5 < 2, avg. 17.2 < 2	Highly dependent on operating procedures. Range: 0.1-0.9 at 12% CO_2, avg. 0.4	Fly Ash SiO_2: 14-52 Al_2O_3: 8-28 Fe_2O_3: 4-19 CaO: 9-22 MgO: 2.8-3.4 $Na_2O + K_2O$: 3-10 TiO_2: 0.7-2.8 Also organic acids and polynuclear hydrocarbons	1.8-3.8	See Figure 24-2 for detailed data		Dependent upon composition of refuse burned
II. Commercial Incinerator		0.06-0.5 at 12% CO_2, avg. 0.2					
III. Apartment House Incinerator		0.02-1.61					

A. Particulate (Part II)

Source	Solubility	Wettability	Hygroscopic Characteristics	Flammability or Explosive Limits	Handling Characteristics	Optical Properties	Odor
I. Municipal Incinerator	Contains water soluble components	Difficult to wet			Agglomerates		
II. Commercial Incinerator	Contains water soluble components	Difficult to wet					
III. Apartment House Incinerator	Contains water soluble components	Difficult to wet					

B. Carrier Gas

Source	Flow Rate	Temperature	Moisture Content	Chemical Composition	Toxicity	Corrosivity	Odor	Flammability or Explosive Limits	Optical Properties
I. Municipal Incinerator	(a) 14-250, avg. 20 (b) 158-288, avg. 220	250-700		CO_2, O_2, CO, N_2, H_2O Typical composition CO_2: 3.7 O_2: 13.0 CO: 0.2 N_2: 64.0 H_2O: 19 Also aldehydes	Dependent upon composition of refuse burned	Dependent upon composition of refuse burned			
II. Commercial Incinerator	(a) 0.01-1 (Limited data)	400-1,400		CO_2, CO, N_2, O_2, H_2O					
III. Apartment House Incinerator	(a) 0.5-2.7 (Limited data)	100-300		CO_2, CO, N_2, H_2O, NO_x, O_2			May be odorous because of incomplete combustion		

[+] See Coding Key, Table 5-1, Chapter 5, page 45, for units for individual effluent properties.

TABLE 24-3

AIR POLLUTION CONTROL SYSTEM AVERAGE CONTROL EFFICIENCY[1]

Type	APC System Removal Efficiency (wt. %) Mineral Particulate	Combustible Particulate[a]	Carbon Monoxide	Nitrogen Oxides	Hydro-carbons	Sulfur Oxides	Hydrogen Chloride	Polynuclear Hydrocarbons[b]	Volatile Metals[c]
None (Flue Settling Only)	20	2	0	0	0	0	0	10	2
Dry Expansion Chamber	20	2	0	0	0	0	0	10	0
Wet Bottom Expansion Chamber	33	4	0	7	0	0	10	22	4
Spray Chamber	40	5	0	25	0	0.1	40	40	5
Wetted Wall Chamber	35	7	0	25	0	0.1	40	40	7
Wetted, Close-Spaced Baffles	50	10	0	30	0	0.5	50	85	10
Mechanical Cyclone (Dry)	70	30	0	0	0	0	0	35	0
Medium Energy Wet Scrubber	90	80	0	65	0	1.5	95	95	80
Electrostatic Precipitator	99	90	0	0	0	0	0	60	90

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a/ Assumed primarily < 5 μ.
b/ Assumed two-thirds condensed on particulate, one-third as vapor.
c/ Assumed primarily a fume < 5 μ.

TABLE 24-4

DISTRIBUTION AND TYPICAL ECONOMICS AMONG INCINERATORS AND APC CONCEPTS[1]

Incineration Systems	1968 Inventory	Average Capacity[c] TPD	Investment $/TPD[c,d]	Operating Costs $/Ton[d]
Type				
1. Continuous, Refractory, Rocking Grate	7.30%	225	$ 6,400	$ 6.16
2. Continuous, Refractory, Reciprocating Grate	4.20	225	6,400	6.16
3. Continuous, Refractory, Traveling Grate	20.87	225	6,400	6.16
4. Continuous, Refractory, Grate & Kiln	7.05	300	5,900	5.75
5. Batch, Refractory, Circular	24.30	130	5,350	6.59
6. Batch, Refractory, Rectangular Cell	23.13	150	5,100	7.16
7. Batch, Refractory, Hearth	13.15	75	5,100	8.56
8. Continuous, Water Wall, Rocking Grate	0.00	350	8,750	5.48
9. Continuous, Water Wall, Reciprocating Grate	0.00	350	8,750	5.48
10. Continuous, Water Wall, Traveling Grate	0.00	350	8,750	5.48
11. Continuous, Water Wall, Suspension Burning	0.00	300	9,350	8.06
12. Continuous, Slagging Type I[a]	0.00	175	11,800	8.83
13. Continuous, Slagging Type II[b]	0.00	225	6,400	6.16
14. Continuous, Fluid Bed	0.00	60	18,400	21.23
15. Continuous, Pyrolysis	0.00	100	7,250	11.94
Total	100.00%			

APC Systems	1968 Inventory	Average Capacity[c] TPD	Investment $/TPD[c,d]	Operating Costs $/Ton[d]
Type				
1. None (Flue settling only)	17.40%		110	0.05
2. Dry Expansion Chamber	21.65		140	0.05
3. Wet Bottom Expansion Chamber	2.09		170	0.14
4. Spray Chamber	12.15		175	0.30
5. Wetted Wall Chamber	16.87		175	0.30
6. Wetted, Close-Spaced Baffles	15.84		215	0.32
7. Mechanical Cyclone (dry)	9.22		340	0.77
8. Medium Energy, Wet Scrubber	4.78		780	0.99
9. Electrostatic precipitator	0.00		900	0.98
10. Fabric Filter	0.00		900	1.10
Total	100.00%			

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a/ Slagging Type I comprises systems where a major part of the system is maintained at temperatures > 2800°F.

b/ Slagging Type II comprises systems where residue fusion takes place almost or entirely as a separate operation.

c/ Capacity expressed in units of tons per 24-hr. day (TPD).

d/ 1969 dollars, 2 shift/day operation.

TABLE 24-5

MAXIMUM DEMONSTRATED COLLECTION EFFICIENCY OF INCINERATOR CONTROL EQUIPMENT[2]

Collection Device	Collection Efficiency (%)
Settling Chamber	35
Wetted Baffles	53
Cyclones	75 to 80
Impaction Scrubbers (with pressure drop less than ten inches of water)	94 to 96
Electrostatic Precipitators	99+

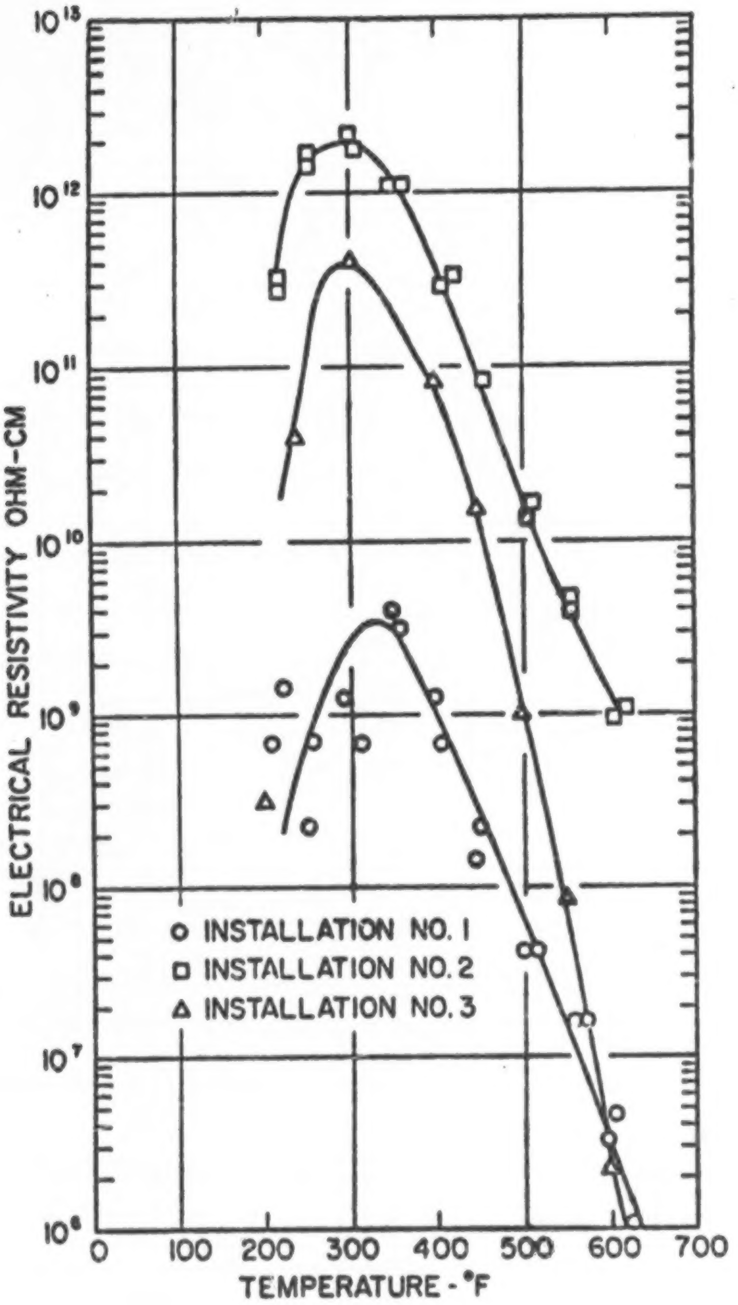

Figure 24-2 - Electrical Resistivity of the < 74 μ Fraction[7]
of Particulate Emission from the Furnace
at 6% Water Vapor

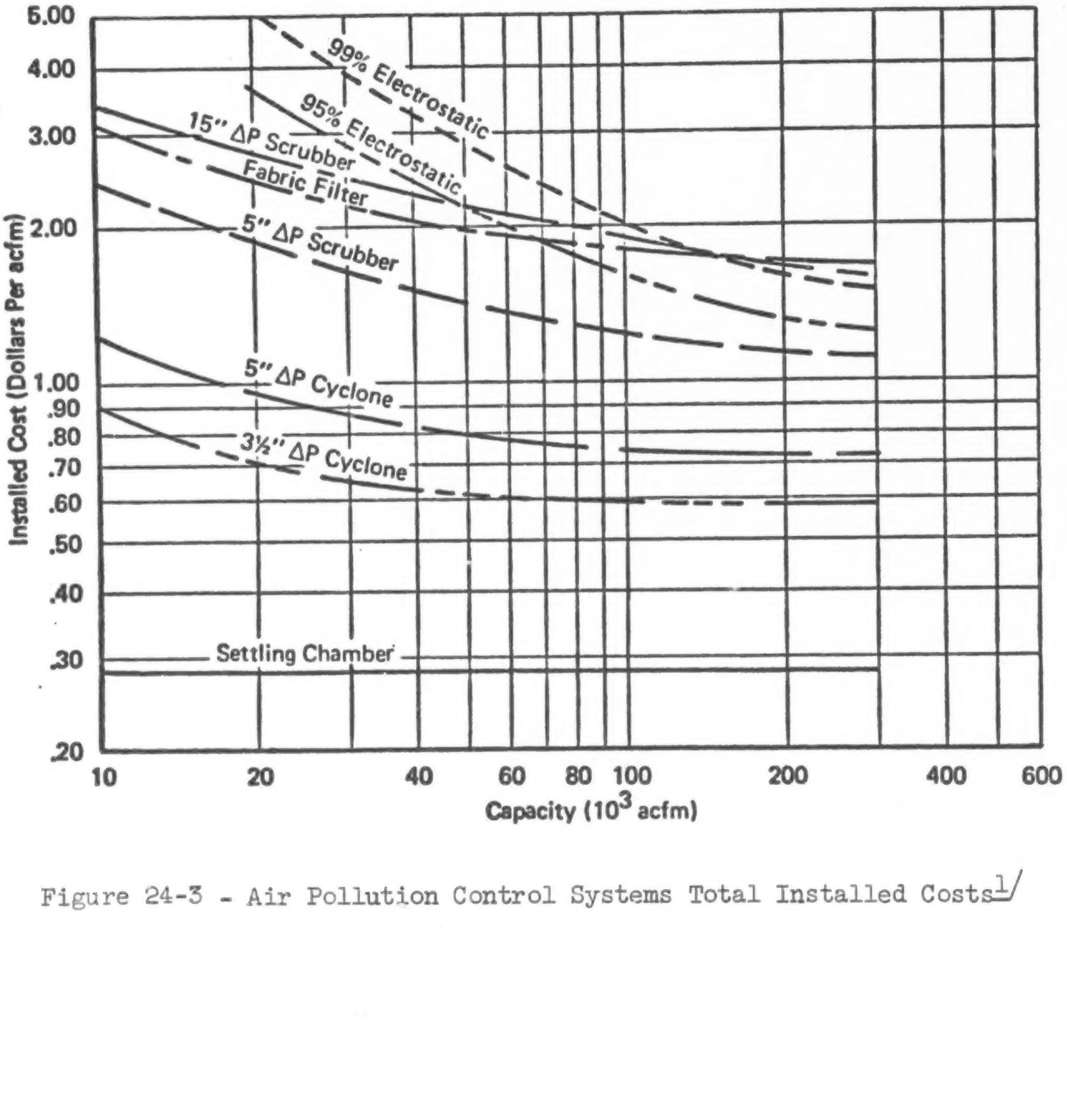

Figure 24-3 - Air Pollution Control Systems Total Installed Costs[1]

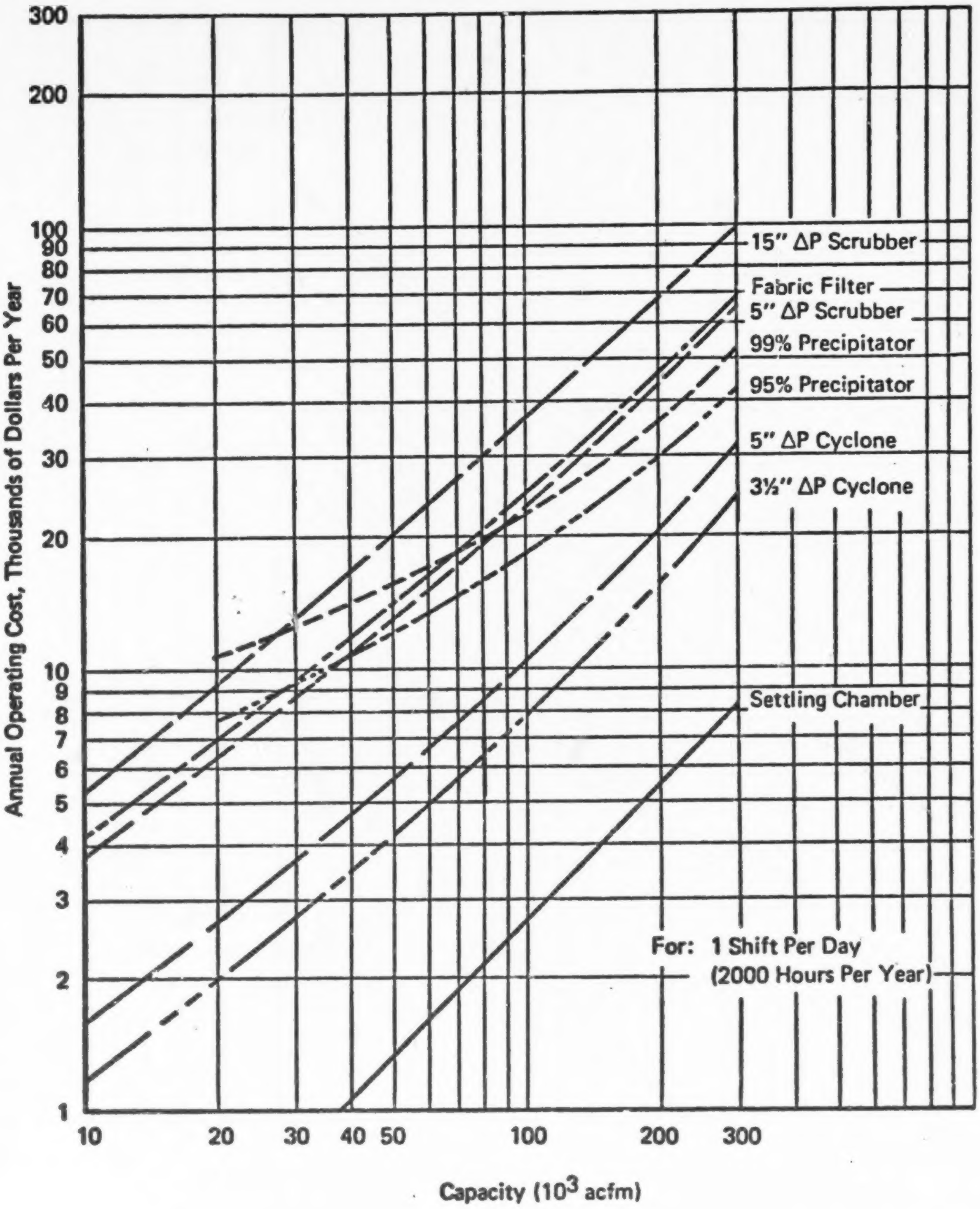

Figure 24-4 - Air Pollution Control Systems Annual Operating Costs[1/]
(1 Shift/Day - 2,000 Hr/Year)

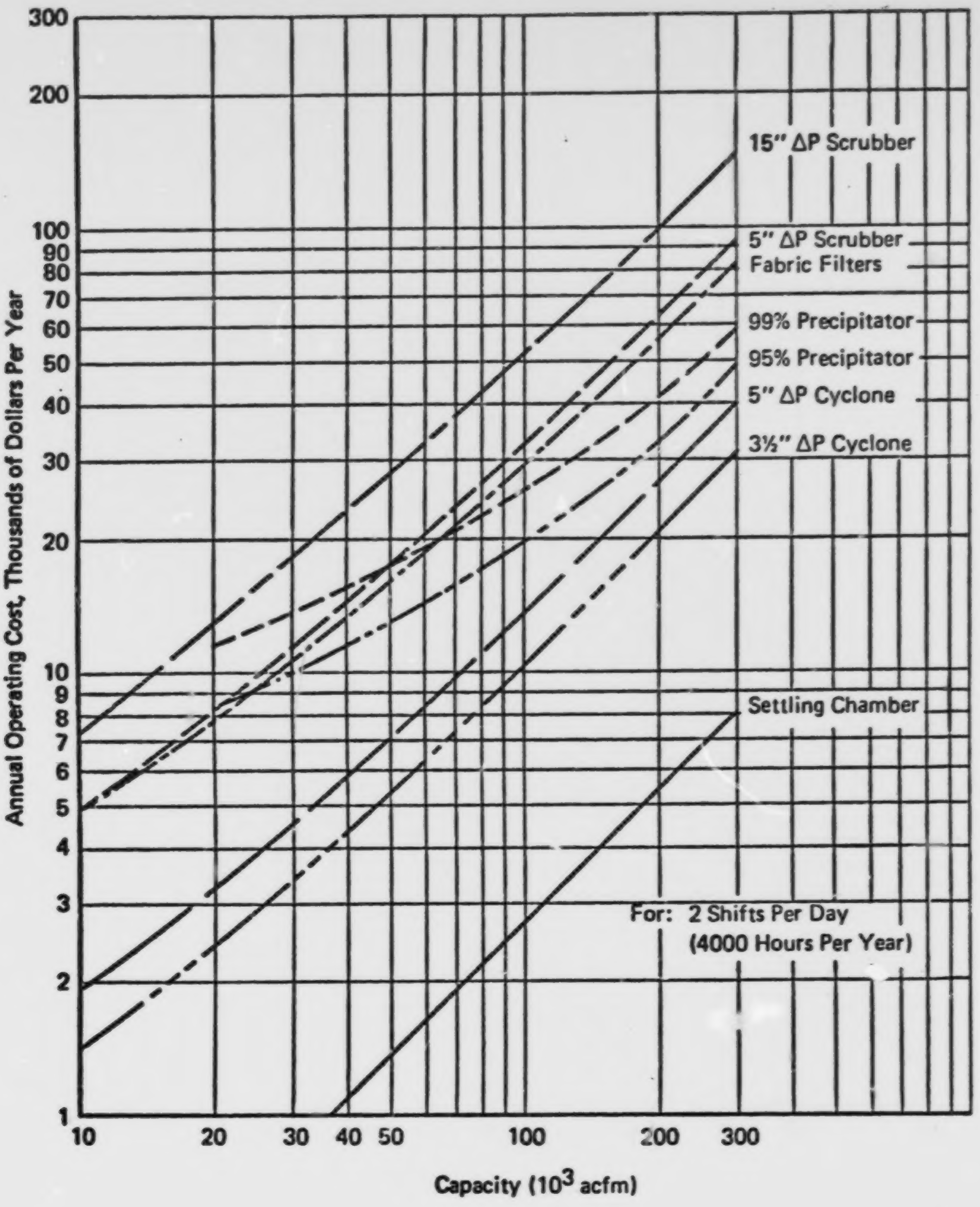

Figure 24-5 - Air Pollution Control Systems Annual Operating Costs[1/]
(2 Shifts/Day - 4,000 Hr/Year)

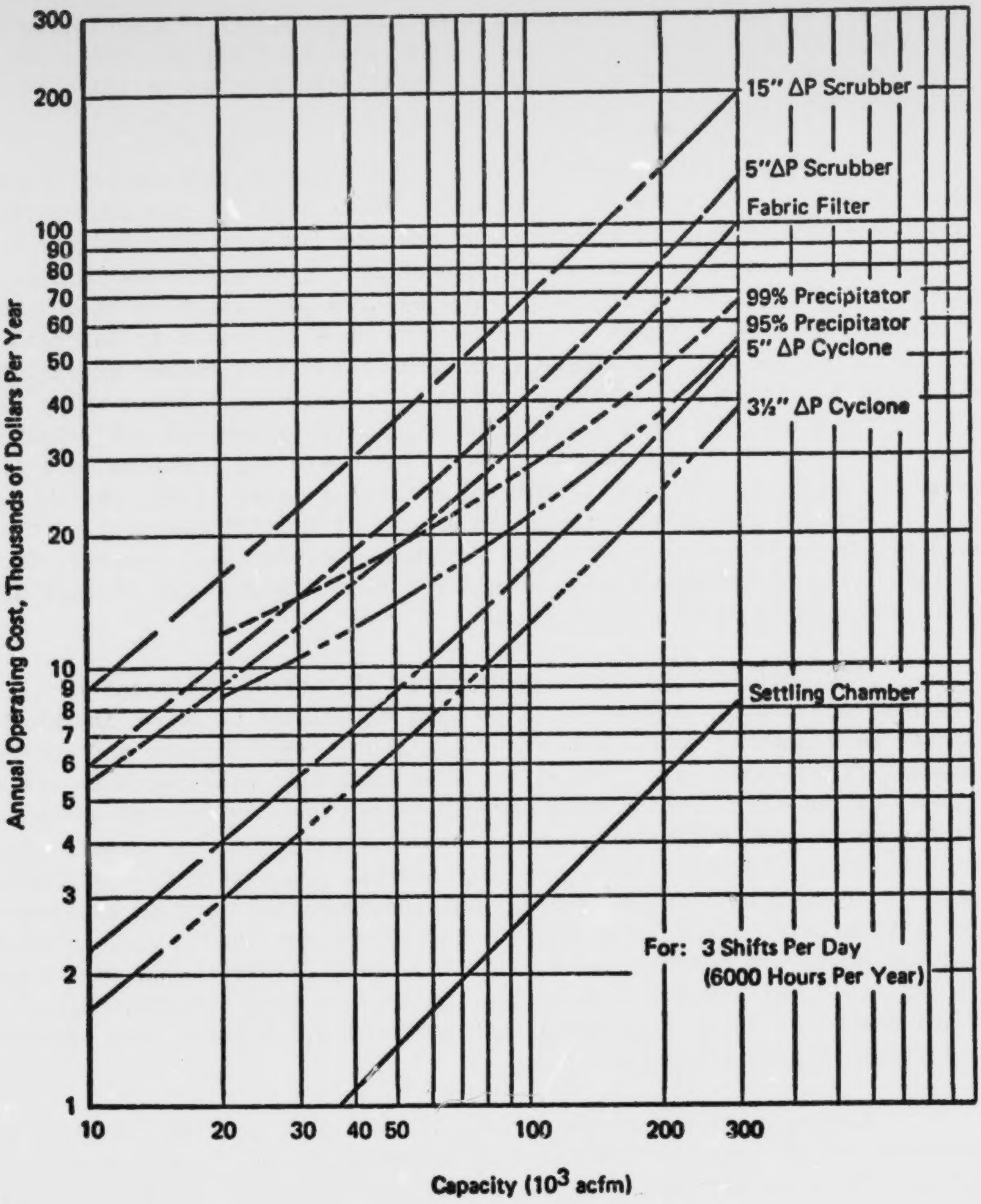

Figure 24-6 - Air Pollution Control Systems Annual Operating Costs[1/]
(3 Shifts/Day - 6,000 Hr/Year)

Figures 24-7 and 24-8 indicate the relationship between collection efficiency and total annual cost (including capital charges). Table 24-6 summarizes the relative in-plant space needs for the air pollution control systems (disregarding auxiliary facilities such as settling ponds, clarifiers, etc.).[1]

Reference 10 describes a study of a proposed 800 ton/day incinerator plant for the District of Columbia. Estimated capital and operating costs for an electrostatic precipitator preceded by a cyclone and for a wet-scrubber system are shown in Table 24-7.[10] The costs shown are as much as 200-300% higher than costs computed from data in Table 24-4. The advantages and disadvantages of both systems were discussed in Reference 10. It is pointed out that the wet scrubber requires a rather extensive water conditioning system and also produces a large vapor plume which may be objectionable. The electrostatic precipitator system had not previously been used in the U. S. and may have potential operating problems such as corrosion, fouling, and inefficient collection of large, flaky particulate matter. Mention was made of the installation of a pilot baghouse on the municipal incinerator of the city of Pasadena, California. However, it was concluded that a baghouse filter should not be considered due to lack of sufficient satisfactory experience.[10]

The cost of applying various types of control equipment to two municipal incinerator designs has also been calculated as shown in Tables 24-8 and 24-9.[11,12] These data are for a 250 ton/day furnace and control equipment efficiencies are typical for that generally attributed to these devices, except that electrostatic precipitators and high-energy wet scrubbers can exceed 99% efficiency but, of course, their cost is higher. Construction costs include cost of cooling chamber, ash separating cyclones, strainers, pumps, baffles, collector, and induced-draft fans as applicable to each alternate. Breechings and stacks are not included. Cooling water and power costs are computed on a 5-1/2 day week, 24 hr/day, 52 weeks/year, at $0.30/1,000 gal and $0.02/kw-hr.[11] These cost data indicate higher control costs (by as much as 200%) than Table 24-4. However, the operating costs are in closer agreement.

Although not a control device, it should be pointed out that the present excess air and the quantity of underfire air can have a very significant effect on the particulates discharged from an incinerator. This will be reflected in the emission and the operation of any associated control devices.[13]

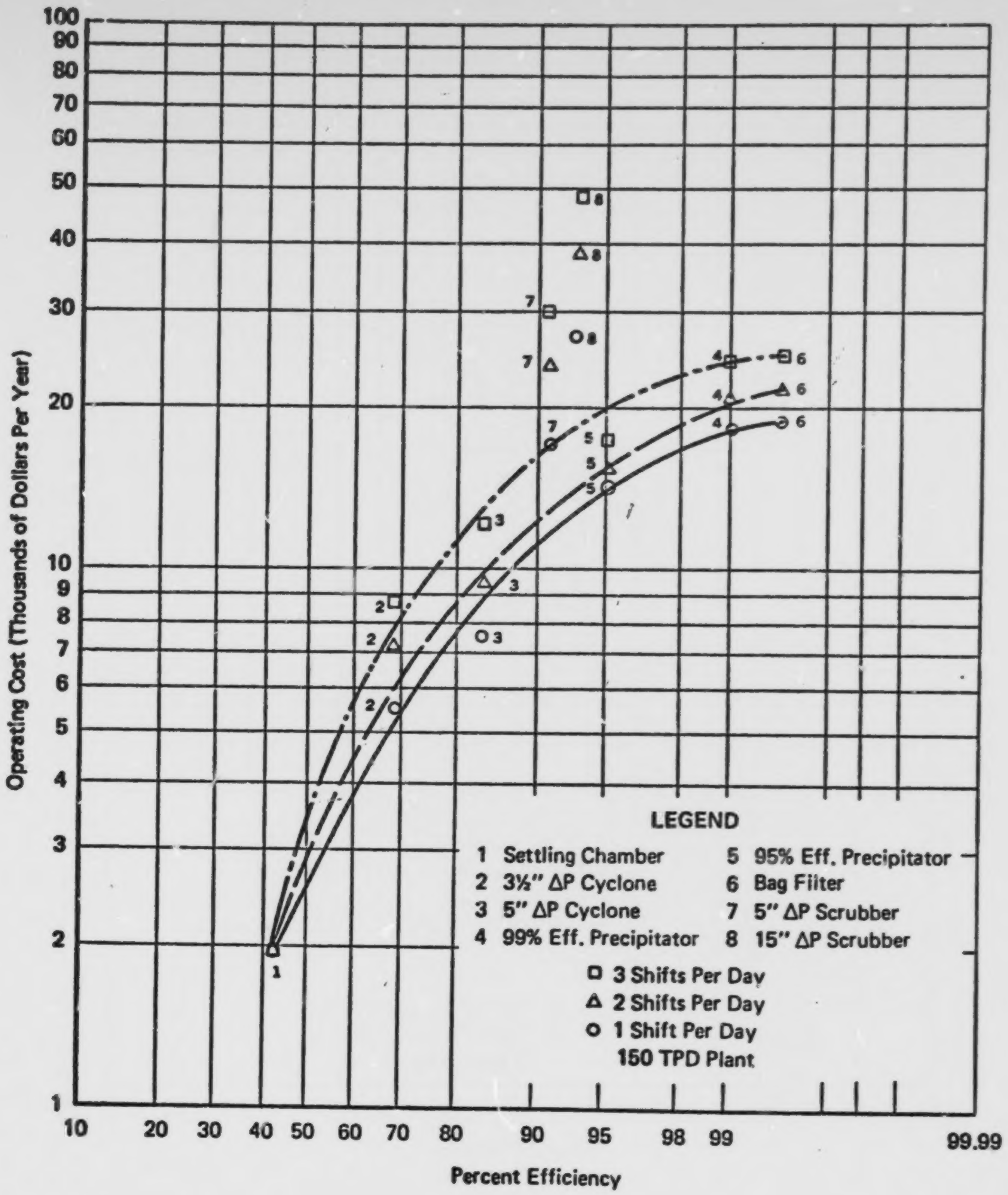

Figure 24-7 - Total Annual Operating Cost vs. Particulate Removal Efficiency, 150 Tons/Day Plant; 1, 2, and 3 Shift Operation[1]

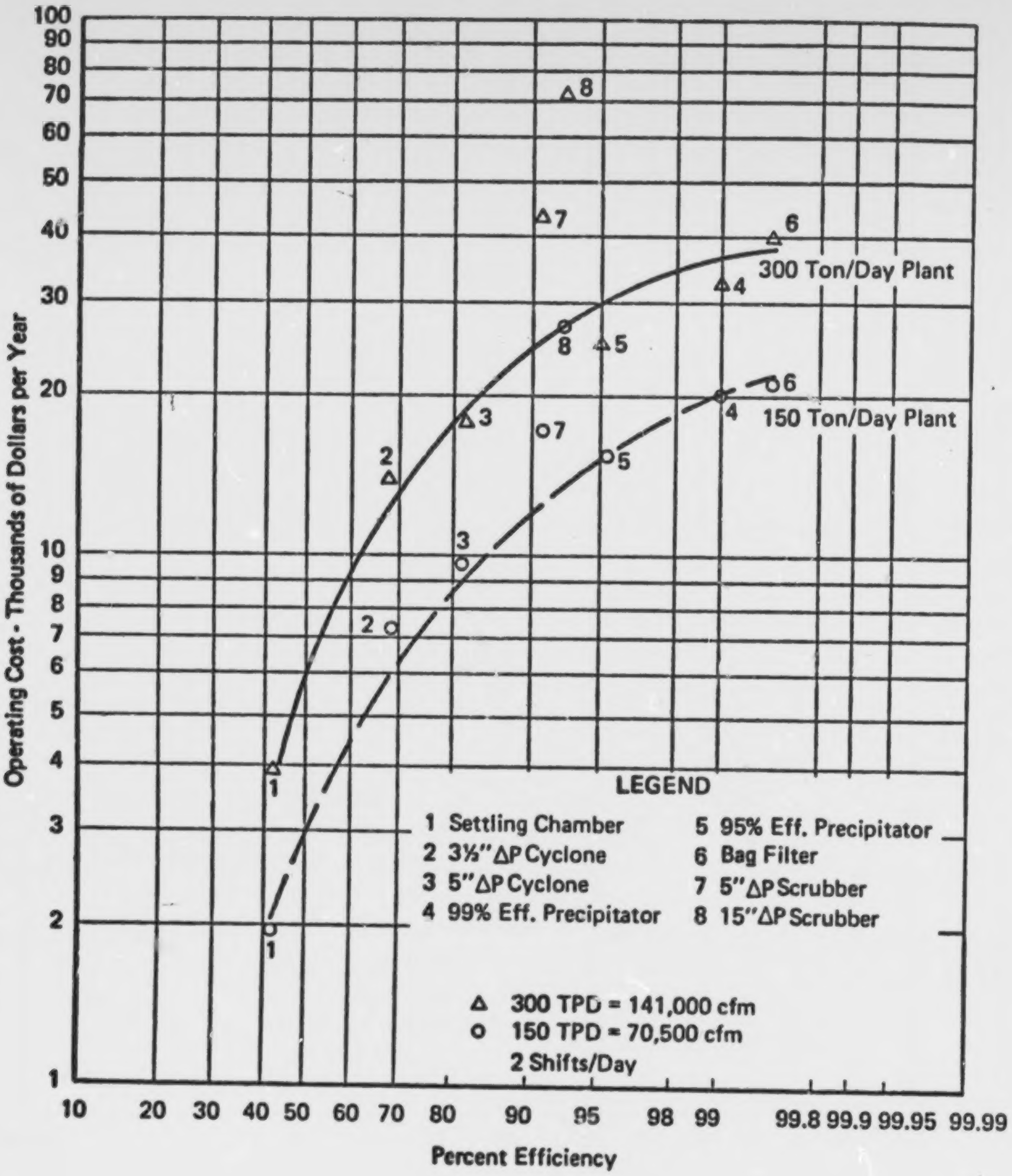

Figure 24-8 - Total Annual Operating Cost vs. Particulate Removal Efficiency, 150 and 300 Tons/Day Plant; 2-Shift Operation[1]

TABLE 24-6

RELATIVE IN-PLANT SPACE REQUIREMENTS FOR AVERAGE AIR POLLUTION CONTROL SYSTEMS[1]

Equipment Type	Relative Space Requirement (%)
Baghouse filter	100
Electrostatic precipitator	90
Scrubber - spray type	50
flooded plate	30
Venturi	25
Mechanical cyclone -	
multiclone	25
60 in. diameter tangential inlet	30
wetted wall	25
Settling chamber with sprays	60

TABLE 24-7

ESTIMATED CAPITAL AND OPERATING COSTS FOR TWO CONTROL SYSTEMS FOR AN 800 TON/DAY INCINERATOR[10]

Type	Capital Cost ($)	Annual Operating Cost ($)
Electrostatic precipitator with mechanical collector	2,409,200	512,500
High energy scrubber	1,838,600	401,000

TABLE 24-8

REFRACTORY FURNACE (250 TONS/DAY) (1966 Costs)[11,12]

Equipment	Efficiency (%)	Stack Outlet a/	Construction Cost ($)	Annual Water Cost ($)	Annual Power Cost ($)	Annual Maint. Cost ($)	Annual Amort. Cost ($)	Cost/Ton Burned ($)
Baffled Spray Chamber	50	1.75	188,200	32,700	6,450	23,700	13,900	0.77
Spray Chamber/Cyclone	78	0.77	237,650	32,700	51,600	10,300	17,550	1.12
Wet Scrubber	96	0.14	400,900	58,400	105,300	16,800	29,400	2.10
Spray Chamber/Precipitator	95	0.175	434,910 = 1,700	32,700	35,300	10,300	32,100	1.10
Spray Chamber/Fabric Collector	99+	< 0.035	622,310	36,600	47,200	33,100	46,100	1.63

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a/ Pounds of particulate/1,000 lb gas at 50% excess air.

TABLE 24-9

WATER COOLED FURNACE (250 TONS/DAY) (1966 Costs)[11,12]

Equipment	Efficiency (%)	Stack Outlet a/	Construction Cost ($)	Annual Water Cost ($)	Annual Power Cost ($)	Annual Maint. Cost ($)	Annual Amort. Cost ($)	Cost/Ton Burned ($)
Cyclone	78	0.77	91,300		29,600	2,000	6,800	0.38
Precipitator	96	0.175	210,300		14,600	9,000	15,600	0.39
Fabric Collector	99+	< 0.085	243,000		34,400	12,100	18,000	0.65

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a/ Pounds of particulate/1,000 lb gas at 50% excess air.

24.2.3.1 Spray Chambers and Wetted Baffles: The most effective spray chambers are those utilizing continuously wetted baffles. The more effective of these involve tortuous gas passages and attendant larger pressure drops. Sprayed-baffle systems with flue-gas pressure drops lower than 0.5 in. are necessary if the use of an induced draft fan is to be avoided. The chamber in which the baffles are installed is normally designed for a baffle slot velocity not exceeding 3,000 ft/min. The water consumption for sprayed baffle systems is normally about 0.5 gpm/ton of refuse burned per day. Natural draft sprayed-baffle systems are capable of meeting a criterion of 0.83 lb. of particulate/1,000 lb of flue gas (at 50% excess air) but may not be suitable for more stringent criteria.[14] The efficiency of wetted baffle collectors on two municipal incinerators has been reported as 53% and 10%.[7,15]

Conversion of a wetted-baffle municipal incinerator to employ neutralization of the water with soda ash to permit recirculation has shown that the savings in water usage will amortize the cost of the additional facilities in less than two years.[15]

24.2.3.2 Wet Scrubbers: Wet scrubbers have been used in a few municipal incinerator applications. Water circulation rates required in scrubbers are high, and this may introduce a disposal problem or require treatment equipment to permit recirculation. The power requirements for the pumps that provide the spray water and for the induced-draft fan system are significant and should be considered in any evaluation.[14] The scrubbers are capable of removing gaseous air pollutants but, in so doing, the acidic solutions that result will require special selection of materials of construction.[14]

It is reported that a Chemico Venturi scrubber is operating on the East 73rd Street incinerator in New York City and is controlling emissions to less than 0.05 grain/scf.[23]

24.2.3.3 Electrostatic Precipitators: Several electrostatic precipitators have been installed and successfully operated in Europe. Some have also been installed in the U. S., as shown in Table 24-10.[24] Several devices with collection efficiencies of over 95% are scheduled for new and existing units.[9] The 1,200 tons/day Des Carrieres Plant in Montreal was to be built with an electrostatic precipitator.[14]

The electrostatic precipitator is capable of high collection efficiencies at low pressure drop. Gas cooling is required for protection of the precipitator from excessive temperatures. Although precipitators do not require the use of an induced-draft fan, such use is normal, primarily to produce a steadier rate of combustion and consequent rate of gas flow, thus making performance more reliable and more predictable.[14]

TABLE 24-10

ELECTROSTATIC PRECIPITATORS INSTALLED ON MUNICIPAL INCINERATORS IN NORTH AMERICA[24]

Location	Collector Manufacturer
Refractory Units	
City of Stamford, Connecticut	Univ. Oil. Prod. (Aerotech)
NYC South Shore Brooklyn	Research-Cottrell
NYC Southwest Brooklyn	Wheelabrator/Lurgi
Dade County, Florida	Wheelabrator/Lurgi
Water-Wall Units	
City of Montreal, Quebec (Von Roll)	Research - Cottrell
City of Braintree, Massachusetts (Detroit Stoker)	Wheelabrator/Lurgi
City of Hamilton, Ontario (C&E Boiler)	Wheelabrator/Lurgi
City of Chicago, Illinois	Wade/Rothemuhle

Major characteristics of European electrostatic precipitator units are shown in Table 24-11.[16] The success of their units is attributed to differences in the design of furnaces, grates and auxiliary equipment.

TABLE 24-11

BASIC DESIGN ELEMENTS OF EUROPEAN ELECTROSTATIC PRECIPITATORS[16]

27 Incinerator Plants
52 Precipitator Units

	Range	Median
Size of Furnaces (tons/day)	42 to 1,060	270
Raw Gas Volume (cfs)	350 to 7,200	1,450
Dust Load in Raw Gas (lb/1,000 lb gas)	2.7 to 12.3	5.43
Gas Entry Temperature (°F)	285 to 520	490
Overall Particulate Cleansing Efficiency (percent)	92.0 to 99.5	98.0

A Swedish article describes the use of multicyclone after collectors following an electrostatic precipitator to reduce emission of paper flakes which are difficult to collect in the precipitator due to their large area, low specific gravity and low resistivity.[17]

24.3 COMMERCIAL INCINERATORS

Commercial and industrial incinerators for burning general refuse may be either single- or multiple-chamber types. The multiple-chamber units are usually associated with large institutional or industrial facilities, while the smaller single-chamber furnaces are used by markets and restaurants.

24.3.1 Emission Sources and Rates

While there are many factors involved in controlling the gaseous and other combustible emissions from commercial types of incinerators, the most important single factor is to maintain a sufficiently high temperature for good combustion. Temperatures above 1000°F can be maintained when burning refuse of low moisture content (after the initial warmup) by maintaining a relatively uniform release of heat from the refuse. This procedure requires frequent charging and stoking by a well-trained operator. In the majority of cases, it is not economically feasible to provide a full-time operator; most incinerators are operated by a janitor or custodian who has many other duties. Therefore, auxiliary fuel has been found to be necessary in almost all cases to maintain temperatures above 1000°F. High temperatures (plus excess air, turbulence,and residence time) effectively oxidize unburned gases and combustible particles and droplets.

Small-sized commercial incinerators with relatively poor combustion produce larger emission rates for polynuclear hydrocarbons than the intermediate and large-sized municipal units. The higher temperatures and longer residence times characteristic of the municipal incinerators account for the lower rates of polynuclear hydrocarbon emission in these units.[18]

Pathological waste incinerators differ from the standard multiple-chamber unit in several respects. Major differences are the use of large burners in the primary chamber, side loading rather than front loading, a solid hearth rather than a grate, and a somewhat different arrangement of the chambers.

No data were found on tonnage of material burned in these units, and estimates of the current level of particulate emissions from commercial and industrial incinerators were not attempted.

24.3.2 Effluent Characteristics

The physical and chemical properties of effluents from industrial and commercial incinerators are outlined in Table 24-2. Limited data are available for these units. Particulate matter emitted is probably larger in size than that discharged from municipal incinerators because of lower quality combustion.

Grain loadings given in Table 24-2 are for units in which good combustion was attained. If these conditions are not met and poor combustion results, clouds of dense smoke are emitted and particulate loadings will be much higher than those shown in Table 24-2.

24.3.3 Control Practices and Equipment

Single-chamber units have generally proven inadequate to meet most emission regulations. Multiple-chamber units produce minimum emissions but may require a good gas washer to meet more stringent regulations. NAPCA has tentatively found that scrubbers having at least 1/2 in. H_2O pressure drop and a water rate of 4 gal/1,000 cfm are required on incinerators to meet emission standards for Federal facilities.[9/]

Design factors for multiple-chamber incinerators are presented and discussed in Reference 3. Initial incinerator cost depends mainly on the capacity of the unit and the degree of air pollution control desired. In a 1966 article, concerning industrial and household incinerators, E. M. Voelker of the Incinerator Institute of America presented the cost of incinerators with varying degrees of control, as shown in Figure 24-9.[19/]

24.4 APARTMENT HOUSE INCINERATORS

Apartment house incinerators have historically been the single chamber flue-fed type. Refuse is charged by tenants through service doors connecting into the flue at each floor. The material accumulates in the furnace and is usually ignited by the janitor or attendant early in the morning. The products of cumbustion pass up the same flue and are discharged to the atmosphere. A screened enclosure or spark arrestor is commonly mounted on top of the flue. Emissions are usually high because of low combustion temperatures and improper air regulation.

24.4.1 Emission Sources and Rates

The incinerator is the only particulate source in this type of installation. Emission rates from these units are highly variable and range from 0.8 to 10 lb/ton of refuse burned.[3,20/] No estimates of national emissions were made for these units.

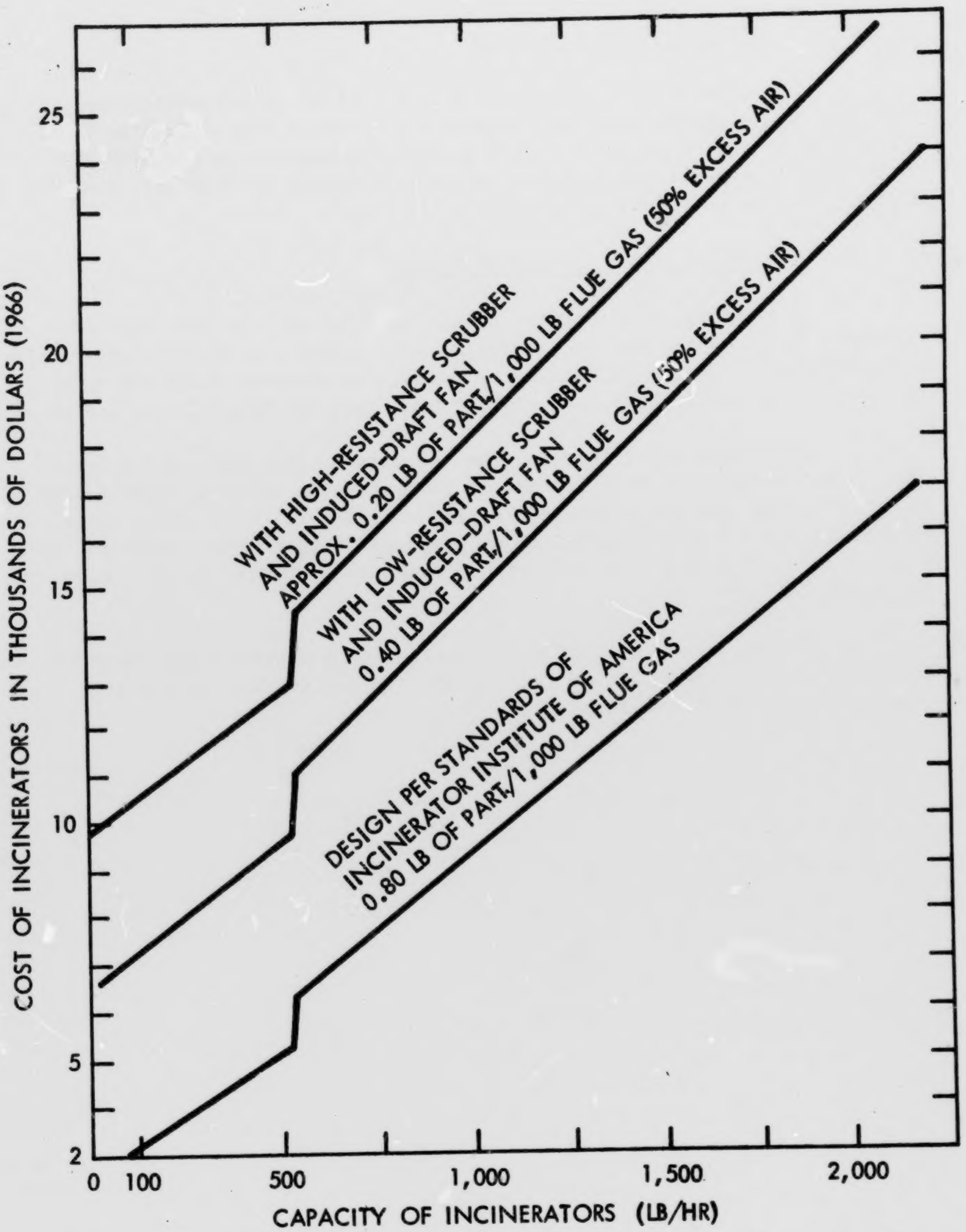

Figure 24-9 - Capital Cost of Incinerators with Varying Degrees of Air Pollution Control Equipment[19]

24.4.2 Effluent Characteristics

The chemical and physical characteristics of effluents from apartment house incinerators are summarized in Table 24-2. Limited data are available for these units. Poor quality combustion is probable for these units and particulate matter emitted is larger in size than that discharged from municipal units.

24.4.3 Control Practices and Equipment

Preventing the discharge of air pollutants from this type of incinerator involves the use of afterburners or conversion to multiple-chamber incineration.[3] Test data, including costs, for various secondary combustion devices and a Peabody gas scrubber are shown in Tables 24-12 and 24-13.[21]

Scrubbers which increase the velocity of the gases and contact them with low-velocity water appear to be preferable to spray nozzle units because plugged nozzles reduce collection efficiency. Evaluation of impingement-type scrubbers operating at pressure drops in the range of 4 to 8 in. w.g. on flue-fed incinerators indicates efficiencies in the range of 78 to 94%.[22]

A preliminary test of a dry cyclone on a flue-fed apartment incinerator showed deposition of fats on the cyclone surface indicating eventual clogging in service.[21]

TABLE 24-12

PEABODY SCRUBBER PERFORMANCE ON FLUE-FED APARTMENT INCINERATORS[23]

Refuse charge, lb/test	275
Scrubber operating time, min.	96
Scrubber exhaust, avg. cfm (corrected to 70°F, 29.22 in. Hg)	2,670
Gas temperature, °F	
Scrubber inlet, range	153-250
Average	196
Scrubber outlet, range	94-108
Average	102
Scrubber trays, number in use	2
Pressure across fan, in. w.g.	7.6
Electric consumption, fan kw.	5.35
pump kw.	0.4
Scrubber water	
Input, gal/hr	60
Evaporated, gal/hr	24
To drain, gal/hr	36
Emissions	
Particulate matter, lb. for test	
Collected by scrubber water, avg.	1.88
In exhaust, avg.	0.12
Scrubber collection efficiency, %	94
Noxious gases, lb. for test, avg.	
In flue gas before scrubber	8.83
In scrubber exhaust	6.92
Removed by scrubber, difference	1.91 lb.
Removal efficiency for noxious gases, %	21.6

TABLE 24-13

PERFORMANCE AND COST OF DEVICES INSTALLED ON APARTMENT INCINERATOR[23]

	Basic Incinerator	Werner Device	One Pipe Overfire Jets	Hartmann Device	Gas Burner and Overfire Jets	Peabody Scrubber	Peabody Scrubber and Overfire Jets
Daily Operation, minutes							
Burning only (no. of burns)	183(2)	38(2)	141(2)	240[a](3)	125[a](2)	183(2)	141(2)
Residue removal	15	15	15	15	15	15	15
Total min., hoppers locked	198	53	156	255	140	198	156
Furnace Capacity, lb	275	240	275	200	275	275	275
Emissions, lb/100 lb of charge							
Particulates	1.31	1.29	0.79	0.72	0.51	0.13[b]	0.09[b]
Noxious gases	2.48	3.01	1.61	1.75	0.73	1.94[c]	1.26[c]
Cost							
Investment	$1,200	$2,700	$1,600	$3,150	$2,200	$5,200	$5,600
Annual, total	166	426	250	1,292	1,117	1,072	1,151
Annual, per room	$0.30	$0.83	$0.49	$2.52	$2.18	$2.09	$2.25

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[a] Adjusted for equal burn-out of residue.
[b] Based on 90% collection of particulate matter.
[c] Based on 22% removal of noxious gases.

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APPENDIX A

ECONOMIC CONSIDERATIONS IN AIR POLLUTION CONTROL

This appendix, illustrating cost relationships for the various types of collectors, has been taken from Chapter 6 of "Control Techniques for Particulate Air Pollutants," U. S. D. H. E. W., Washington, D. C., 1969. It contains three curves for each type of collector showing purchase cost, installed cost, and annualized cost of operation, as a function of gas volume handled in acfm. It also contains cost data and equations for the determination of operating and maintenance cost for each type of collector.

This cost information contains an explanation of all assumptions and cost bases used. It is included as a basis for cost comparisons with data presented in the industry chapters and as a source of data for the reader's own use in estimating the cost of collection equipment.

A.1 SELECTION OF CONTROL SYSTEM

Most air pollution emission control problems can be solved in several ways. In order to select the best method of reducing pollutant emissions, each solution should be thoroughly evaluated prior to implementation. Steps such as substitution of fuels and raw materials and modification or replacement of processes should not be overlooked as possible solutions. Such emission reduction procedures often can improve more than one pollution problem. For example, particulate matter and sulfur oxides emissions both may be reduced by switching from high-sulfur coal to natural gas or low-sulfur oil. Such steps also may have the benefit of reducing or eliminating solid waste disposal and water pollution problems. Often it is cheaper to attack two air problems together than to approach each problem individually. If steps such as process alterations and substitution of fuels are not feasible, it may be necessary to use gas-cleaning equipment.

Figure A-1 shows the factors to be considered in selection of gas-cleaning system. The first consideration is the degree of reduction of emissions which may be required to meet emission standards. The degree of emission reduction or the collection efficiency required is dependent upon the relationship between emissions and emission standards as shown at the top of the figure. This is an important factor in making the choice among control equipment alternatives. Although a control system may include two or more pieces of control equipment, collection efficiency, as used in this chapter, applies to individual pieces of control equipment. The usual ranges of collection efficiency for various equipment alternatives are shown in

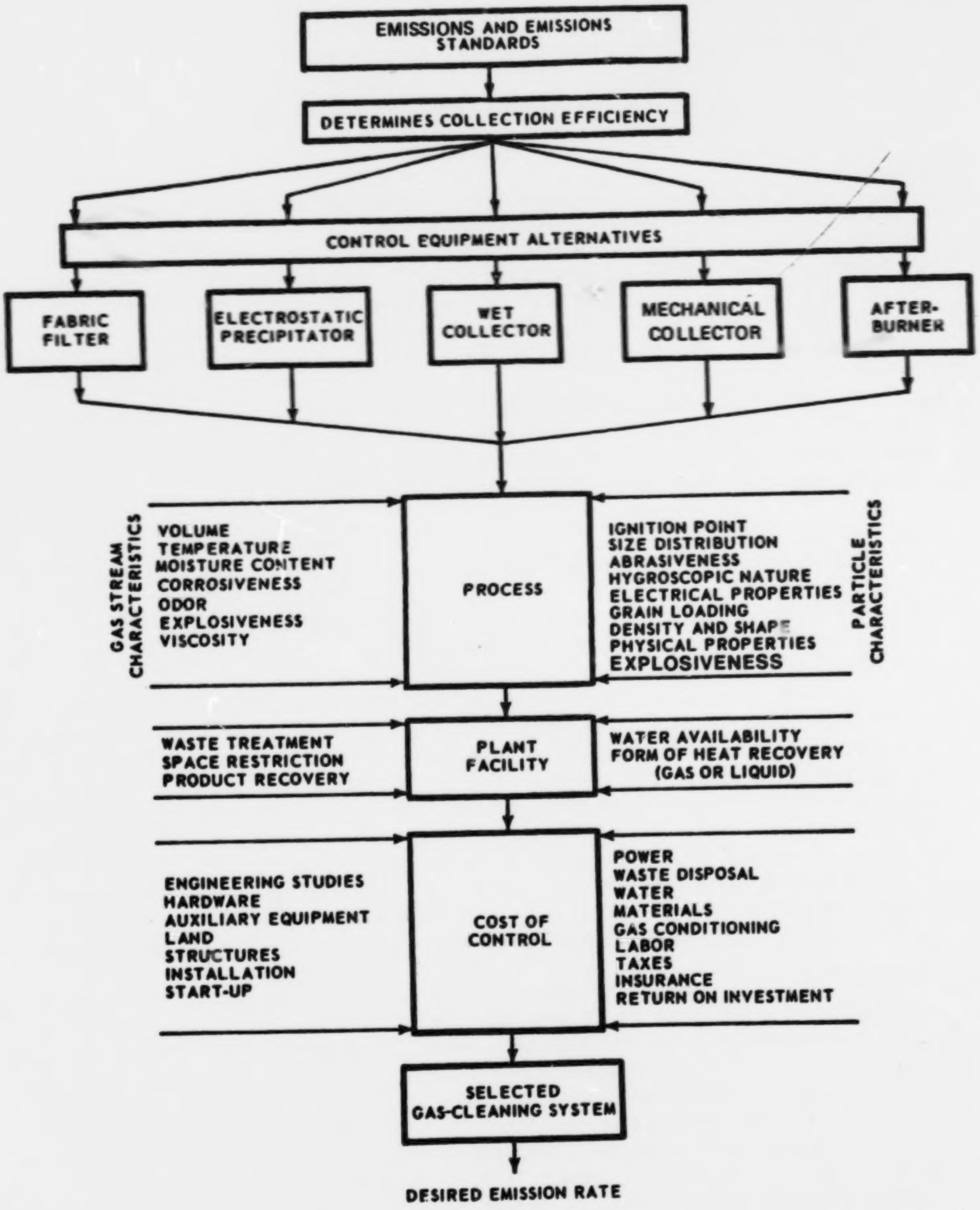

Figure A-1 - Criteria for Selection of Gas-Cleaning Equipment

Table A-1. The important factors to be considered next are the gas stream and particle characteristics of the process itself, as shown in the center of Figure A-1. High gas temperatures without cooling, for example, preclude the use of fabric filters; explosive gas streams prohibit the use of electrostatic precipitators; and submicron particles cannot generally be efficiently collected with mechanical collectors. A number of factors that relate to the plant facility should also be considered, some of which are listed in Figure A-1. Each alternative will have a specific cost associated with it, and the components of this cost should be carefully examined. Those alternatives which meet the requirements of both the process and the plant facility can then be evaluated in terms of cost; on this basis, the gas-cleaning system may be selected.

TABLE A-1

AIR POLLUTION CONTROL EQUIPMENT COLLECTION EFFICIENCIES[1-3]

Equipment Type	Efficiency Range (on a total weight basis) (%)
Electrostatic precipitator[a]	80 to 99.5+
Fabric filters[b]	95 to 99.9
Mechanical collector	50 to 95
Wet collector	75 to 99+
After burner:	
Catalytic[c]	50 to 80
Direct flame	95 to 99

---

[a] Most electrostatic precipitators sold today are designed for 98 to 99.5% collection efficiency.

[b] Fabric filter collection efficiency is normally above 99.5%.

[c] Not normally applied in particulate control; has limited use because most particulates poison or desensitize the catalyst.

A.2 COST-EFFECTIVENESS RELATIONSHIPS

Meaningful quantitative relationships between control costs and pollutant reductions are useful in assessing the impact of control on product prices, profits, investments, and value added to the product.* With such relationships at hand the alternates for solution of an air pollution problem can be evaluated for more effective program implementation by the user of the control equipment and by the enforcement agency. These cost-effectiveness relationships sometimes are applied collectively to a meteorological or air quality control region, where they describe the total cost impact on polluters as a result of controlling sources; the discussion here, however, centers around cost-effectiveness as applied to an individual source. Cost-effectiveness is a measure of all costs to the firm associated with a given reduction in pollutant emissions. For computing the costs for a given system, one should consider (1) raw materials and fuels used in the process, (2) alterations in process equipment, (3) control hardware and auxiliary equipment, and (4) disposal of collected emissions.

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* Value added is generally considered to be the economic worth added to a product by a particular process, operation, or function.[4]

Figure A-2 shows an example of a theoretical cost-effectiveness relationship.[5] The actual total costs of control may depart from this curve because some cost elements, such as research and development expenditures and fixed charges (taxes, insurance, depreciation) are not directly related to the operation of the equipment and to the level of emissions in a given year. The cost of control is represented on the vertical axis and the quantity of pollutants emitted on the horizontal axis. Point P indicates the uncontrolled state, in which there are no control costs. As control efficiency improves, the quantity of emissions is reduced and the cost of control increases. In most cases, the marginal cost of control is smaller at the lower levels of efficiency, near Point P of the curve. The curve also illustrates that as the cost of control increases, greater increments of cost usually are required for corresponding increments of emission reduction. Process changes sometimes may result in emission reduction without increased costs. Research and development expenditures resulting in new or improved equipment design, improved process operations, or more efficient equipment operations will improve the economics of control. All these factors may substantially reduce control costs at most emission levels and shift the cost of the control curve (CC) as illustrated by CC_1 in Figure A-3. Note that as control technology develops, the cost of attaining a desired emission level will be reduced from C_a to C_b.

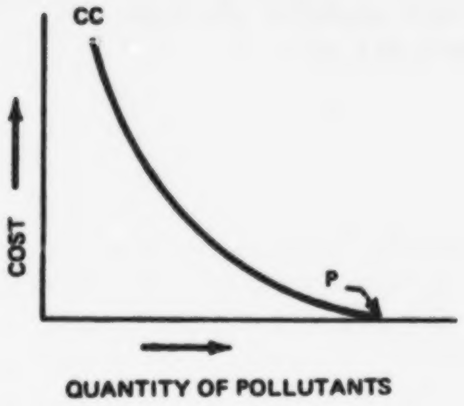

Figure A-2 - Cost of Control

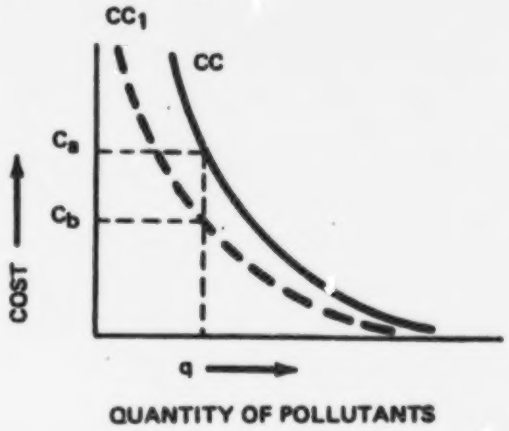

Figure A-3 - Expected New Cost of Control

Cost-effectiveness information is useful in emission control decision-making. Several feasible systems usually are available for controlling each source of emissions. In most cases, the least-cost solution for each source can be calculated at various levels of control. After evaluating each alternative and after considering future process expansions and more rigid control restrictions, sufficient information should be available on which to base an intelligent control decision.

Cost-effectiveness relationships vary from industry to industry and from plant to plant within an industry. The cost for a given control system is significantly dependent on the complexity of the installation and the characteristics of the gas stream and pollutant. Geographical location is another significant factor that influences the total annual cost; for example, the components of annual cost, such as utilities, labor, and the availability of desired sites for waste material, vary from place to place.

A.3 COST DATA

It is the purpose of this Appendix to develop basic information and techniques for estimating the costs of installing and operating control equipment. Such information can be useful in developing cost-effectiveness relationships for application of various control systems.

A.4 UNCERTAINTIES IN DEVELOPING COST RELATIONSHIPS

Cost information for control devices is given in Section A.7 where, for various types of equipment, operating capacity is plotted against cost. The upper and lower curves indicate the expected range of costs, with the expected average cost falling approximately in the middle. Although quantitative values for collection efficiency and gas volume capacity are not listed, higher collection efficiency, which involves more intricate engineering design, results in higher costs. Control equipment is designed for a nominal gas volume capacity, but under actual operating conditions the volume may vary. Similarly, the efficiency of control equipment will vary from application to application as particle characteristics, such as wettability, density, shape, and size distribution, differ. For example, a control device designed to operate on 50,000 acfm of gas with a nominal collection of 95% may have an effective operating range of from 45,000 to 55,000 acfm, and its collection efficiency may range from 90 to 97%.

The effect of these independent variations is to make single point estimates of cost versus size and efficiency difficult to determine. Based on the data available, all estimates must be constructed over an interval of uncertainty for each of the three variables. To make the cost estimation problem manageable in this report, nominal high, medium, and low collection efficiencies have been selected for each type of control equipment, except fabric filters. For fabric filters, the nominal high, medium, and low curves reflect construction variations. The purchase, installation, and total annualized costs of operation are plotted for each of the three efficiency levels over the gas volume range indicated. Purchase, installation, and total annumalized costs for fabric filters are plotted for variations in filter construction and cleaning methods.

Generalized categories of control equipment are discussed rather than specific designs because of uncertainties in size, efficiency, and cost. If required, more detailed information on the cost of various engineering innovations (e.g., packed towers of specific design to accommodate a corrosive gas stream) should be requested from the manufacturers of the specific equipment. Cost variations associated with wet collectors are reported in Table A-2.[3]

Other difficulties exist in developing cost information for existing control devices, especially cost estimates on the maintenance and operation of control equipment. Individual firms may remember what a control device cost originally, but they may forget what it costs to install and operate. In addition, internal bookkeeping and auditing systems often bury these expenditures in total plant operating costs. For example, water and electricity used by a control operation are not always separately metered and accountable as a specific air pollution control cost item. Some of these costs can be identified and assessed on the basis of industrial experience or engineering estimates.

TABLE A-2

APPROXIMATE COST OF WET COLLECTORS IN 1965[3]

Type of Collector[a]	Cost, dollars/cfm Capacity, cfm 1,000	5,000	20,000	40,000
Cyclonic:[b,c]				
Small diameter multiples	0.50	0.30	0.20	0.20
Single chamber, constant water level	1.40	0.45	0.35	0.25
Single chamber, multiple stage, overhead line pressure water feed	0.95	0.40	0.25	0.20
Single chamber, internal nozzle spray	3.00	1.50	1.00	0.75
Self-induced spray[b-d]	0.80	0.40	0.25	0.25
Wet impingement[b,c]	1.00	0.50	0.25	0.25
Venturi[c,d]	3.00	1.50	1.20	0.50
Variable pressure drop inertial[c,d]	1.00	-	-	0.30
Mechanical[c,d]	1.75	0.75	0.35	-

---

[a] Basic designs, mild steel construction.

[b] Add 30 to 40% to base price for fan, drive, and motor (standard construction materials).

[c] Special materials construction costs for 1,000- to 40,000-cfm range units are approximately as follows:

Rubber lining - base increase of 65 to 115%.
Type 304 stainless steel - base increase of 30 to 60%.
Type 316 stainless steel - base increase of 45 to 100%.

[d] Add from 10 to 40% to base price per additional stage as in some cyclonic and wet impingement designs

A.5 DESCRIPTION OF CONTROL COST ELEMENTS

A.5.1 General

The actual cost of installing and operating air pollution control equipment is a function of many direct and indirect cost factors. An analysis of the control costs for a specific source should include an evaluation of all relevant factors, as outlined in Figure A-4. The control system must be designed and operated as an integral part of the process; this will minimize the cost of control for a given emission level. The definable control costs are those that are directly associated with the installation and operation of control systems. These expenditure items from the viewpoint of the control equipment user have a breakdown for accounting purposes as follows:

Capital Investment
  Engineering studies
  Land
  Control hardware*
  Auxiliary equipment*
  Operating supply inventory
  Installation*
  Startup
  Structure modification

Maintenance and Operation
  Utilities*
  Labor*
  Supplies and materials*
  Treatment and disposal of collected material

Capital Charges
  Taxes*
  Insurance*
  Interest*

---

* Denotes cost items considered in this report.

Of the expenditure items shown above, only those denoted by an asterisk were considered in developing the cost estimates used in this Appendix. Other factors, such as engineering studies, land acquisition, operating supply inventory, and structural modification, vary in cost from place to place and therefore were not included. Costs for the treatment and disposal of collected material, while also not included, are discussed in some detail in Section A.8.

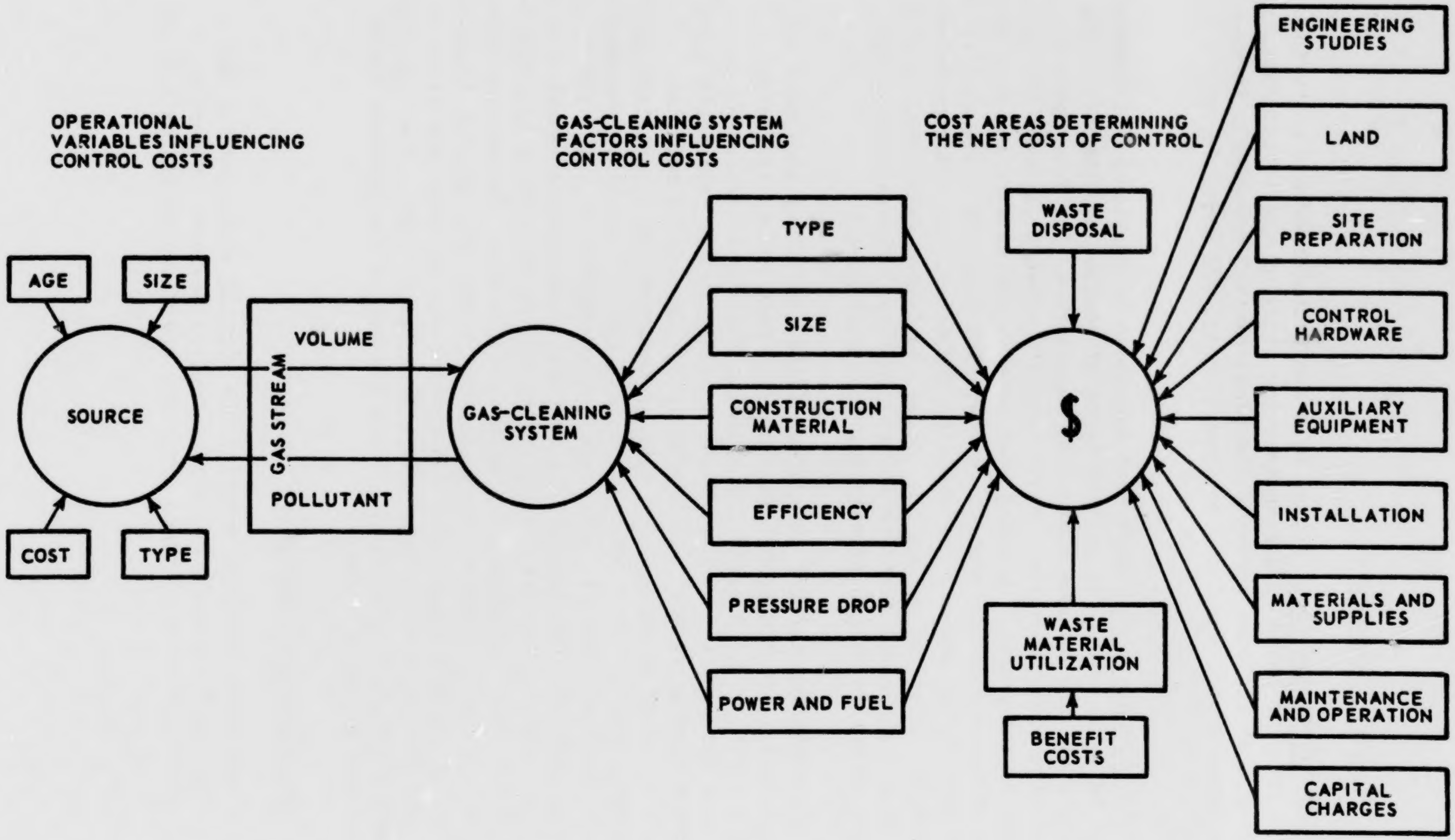

Figure A-4 - Diagram of Cost Evaluation for a Gas-Cleaning System

A.5.2 Capital Investment

The "installed cost" quoted by a manufacturer of air pollution equipment usually is based on his engineering study of the actual emission source. This cost includes three of the eight capital investment items--control hardware costs, auxiliary equipment costs, and costs for field installation.

The purchase cost curves that are shown in Section A.7 illustrate the control hardware costs for various types of control equipment. These purchase costs are the amounts charged by manufacturer for equipment of standard construction materials. Basic control hardware includes built-in instrumentation and pumps. Purchase cost usually varies with the size and collection efficiency of the control device. The purchase costs plotted on the curves are typical for the efficiencies indicated, but these costs may vary ± 20% from the values shown. Of course, equipment fabricated with special materials (e.g., stainless steel or ceramic coatings) for extremely high temperatures or corrosive gas streams may cost much more.

The remaining capital investment items, auxiliary equipment and installation costs, are aggregated together and referred to as "total installation costs." These costs are shown in Table A-3, expressed as percentages of the purchase costs. These costs include a reasonable increment for the following items: (1) erection, (2) insulation material, (3) transportation of equipment, (4) site preparation, (5) clarifiers and liquid treatment systems (for wet collectors), and (6) auxiliary equipment such as fans, ductwork, motors, and control instrumentation. The low values listed in the table are for minimal transportation and simple layout and installation of control devices. High values are for higher transportation cost and for difficult layout and installation problems. The extreme high values are for unusually complex installations on existing process equipment. Table A-4 lists the major cost categories and related conditions that establish the installation cost range from low to high. The "installed cost" estimates reported in Section A-7 are the sum of the purchase costs and the total installation costs.

A.5.3 Maintenance and Operation

The following sections describe the working equations for the operation and maintenance costs of various control devices. Numerical values for the variables expressed in these equations are found in Tables A-5 and A-6.

TABLE A-3

TOTAL INSTALLATION COST FOR VARIOUS TYPES OF CONTROL DEVICES EXPRESSED AS A PERCENTAGE OF PURCHASE COSTS

Equipment Type	Cost, Percent			
	Low	Typical	High	Extreme High
Gravitational	33	67	100	-
Dry centrifugal	35	50	100	400
Wet collector:				
Low, medium energy	50	100	200	400
High energy[a]	100	200	400	500
Electrostatic precipitators	40	70	100	400
Fabric filters	50	75	100	400
Afterburners	10	25	100	400

---

[a] High-energy wet collectors usually require more expensive fans and motors.

TABLE A-4

CONDITIONS AFFECTING INSTALLED COST OF CONTROL DEVICES

Cost Category	Low Cost	High Cost
Equipment transportation	Minimum distance; simple loading and unloading procedures	Long distance; complex procedure for loading and unloading
Plant age	Hardware designed as an integral part of new plant	Hardware installed into confines of old plant requiring structural or process modification or alteration
Available space	Vacant area for location of control system	Little vacant space requires extensive steel support construction and site preparation
Corrosiveness of gas	Noncorrosive gas	Acidic emissions requiring high alloy accessory equipment using special handling and construction techniques
Complexity of startup	Simple startup, no extensive adjustment required	Requires extensive adjustments; testing; considerable down time
Instrumentation	Little required	Complex instrumentation required to assure reliability of control or constant monitoring of gas stream
Guarantee on performance	None needed	Required to assure designed control efficiency
Degree of assembly	Control hardware shipped completely assembled	Control hardware to be assembled and erected in the field
Degree of engineering design	Autonomous "package" control system	Control system requiring extensive integration into process, insulation to correct temperature problem, noise abatement
Utilities	Electricity, water, waste disposal facilities readily available	Electrical and waste treatment facilities must be expanded, water supply must be developed or expanded
Collected waste material handling	No special treatment facilities or handling required	Special treatment facilities and/or handling required
Labor	Low wages in geographical area	Overtime and/or high wages in geographical area

TABLE A-5

ANNUAL MAINTENANCE COSTS FOR ALL GENERIC TYPES OF CONTROL DEVICES

Generic Type	Dollars Per ACFM Low	Dollars Per ACFM Typical	Dollars Per ACFM High
Gravitational and dry centrifugal collectors	0.005	0.015	0.025
Wet collectors	0.02	0.04	0.06
Electrostatic precipitators:			
High voltage	0.01	0.02	0.03
Low voltage	0.005	0.014	0.02
Fabric filters	0.02	0.05	0.08
Afterburners:			
Direct flame	0.03[a]	0.06[b]	0.10[b]
Catalytic	0.07	0.20	0.35

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[a] Metal liner with outside insulation.

[b] Refractory lined.

TABLE A-6

MISCELLANEOUS COST AND ENGINEERING FACTORS

<table>
<tr><td colspan="4">Fan Efficiency = 60% Pump Efficiency = 50%</td></tr>
<tr><td colspan="4">Power Cost, Dollars/Kilowatt-Hr[a]</td></tr>
<tr><td></td><td>Low</td><td>Typical</td><td>High</td></tr>
<tr><td>All devices</td><td>0.005</td><td>0.011</td><td>0.020</td></tr>
<tr><td colspan="4">Hours of Operation
8,760 hr/yr - 24 hr/day x 365 days/yr = 8,760</td></tr>
<tr><td colspan="4">Power requirements vs. efficiency for high-voltage electrostatic precipitators, 10^{-3} kw/acfm</td></tr>
<tr><td></td><td>Low</td><td>Medium</td><td>High</td></tr>
<tr><td></td><td>0.19</td><td>0.26</td><td>0.40</td></tr>
<tr><td colspan="4">Power requirements vs. efficiency for low-voltage electrostatic precipitators 10^{-3} kw/acfm</td></tr>
<tr><td colspan="2">Low</td><td colspan="2">High</td></tr>
<tr><td colspan="2">0.015</td><td colspan="2">0.040</td></tr>
<tr><td colspan="4">Liquor cost in 10^{-3} dollars/gal (for wet system)</td></tr>
<tr><td></td><td>Low</td><td>Typical</td><td>High</td></tr>
<tr><td>Wet scrubber</td><td>0.35</td><td>0.50</td><td>1.00</td></tr>
<tr><td colspan="4">Makeup liquor requirements, 0.0005 gal/hr-acfm</td></tr>
<tr><td colspan="4">Power Requirements</td></tr>
<tr><td></td><td>Low Efficiency</td><td>Medium Efficiency</td><td>High Efficiency</td></tr>
<tr><td>"Scrubbing" (contact) power, horsepower/acfm</td><td>0.0013</td><td>0.0035</td><td>0.015</td></tr>
<tr><td colspan="4">Scrubber Liquor Data</td></tr>
<tr><td></td><td>Low</td><td>Typical</td><td>High</td></tr>
<tr><td>Liquor circulation rate, gal/acfm</td><td>0.001</td><td>0.008</td><td>0.020</td></tr>
<tr><td>Minimum head requirements, feet water</td><td>1[b]</td><td>30</td><td>60</td></tr>
<tr><td colspan="4">Pressure drop through equipment, inches of water</td></tr>
<tr><td>Generic Type</td><td>Low</td><td>Typical</td><td>High</td></tr>
<tr><td>Dry centrifugal collector</td><td>-</td><td>2-3</td><td>4</td></tr>
<tr><td>Fabric filter</td><td>2-3</td><td>4-5</td><td>6-8</td></tr>
<tr><td>Afterburners</td><td>0.5</td><td>1.0</td><td>2</td></tr>
<tr><td>Electrostatic precipitators and gravitational collectors</td><td>0.1</td><td>0.5</td><td>1</td></tr>
</table>

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[a] Based on national average of large consumers.

[b] 1 psig = 2.3 ft. water.

A.5.3.1 General: The costs of operation and maintenance will vary widely because of different policies of control equipment users. This variance will depend on such factors as the quality and suitability of the control equipment, the user's understanding of its operation, and his vigilance in maintaining it. Maintenance and operation usually are very difficult to define and assess, but often may be a significant portion of the overall cost of controlling air pollutant emissions. Although the combined operating and maintenance costs may be as low as 10% of the annualized total cost for a gravitational settling chamber, for example, they may be as high as 90% of the total annualized cost for a high-efficiency wet collector.

Maintenance cost is the expenditure required to sustain the operation of a control device at its designed efficiency with a scheduled maintenance program and necessary replacement of any defective parts. On an annual basis, maintenance cost in the following equations is assumed proportional to the capacity of the device in acfm. Table A-5 shows annual maintenance cost factors for all types of particulate control devices. Simple, low-efficiency control devices have low maintenance costs; complex, high-efficiency devices have high maintenance costs.

Annual operating cost is the expense of operating a control device at its designed collection efficiency. This cost depends on the following factors: (1) the gas volume cleaned, (2) the pressure drop across the system, (3) the operating time, (4) the consumption and cost of electricity, (5) the mechanical efficiency of the fan, and (6) the scrubbing-liquor consumption and costs (where applicable).

A.5.3.2 Gravitational and Centrifugal Mechanical Collectors: In general, the only significant cost for operating mechanical collectors is the electric power cost, which varies with the unit size and the pressure drop. Since pressure drop in gravitational collectors is low, operational costs associated with these units are considered to be insignificant. Maintenance cost includes the costs of servicing the fan motor, replacing any lining worn by abrasion, and, for multicyclone collectors, flushing the clogged small diameter tubes.

Cost equation - The theoretical annual cost (G) of operation and maintenance for centrifugal collectors can be expressed as follows:

$$G = S\left[\frac{0.7457\ PHK}{6356E} + M\right] \qquad (1)$$

where:

S = design capacity of the collector, acfm

P = pressure drop, inches of water (see Table A-6)

E = fan efficiency, assumed to be 60% (expressed as 0.6)

0.7457 = a constant (1 horsepower = 0.7457 kilowatt)

H = annual operating time (assumed 8,760 hr.)

K = power cost, dollars/kilowatt-hr (see Table A-6)

M = maintenance cost, dollars/acfm (see Table A-5)

For computational purposes the cost formula can be simplified as follows:

$$G = S \left[195.5 \times 10^{-6}\ PHK + M \right] \qquad (2)$$

A.5.3.3. Wet Collectors: The operating costs for a wet collector include power and scrubbing-liquor costs. Power costs vary with equipment size, liquor circulation rate, and pressure drop. Liquor consumption varies with equipment size and stack gas temperature. Maintenance includes servicing the fan or compressor motor, servicing the pump, replacing worn linings, cleaning piping, and any necessary chemical treatment of the liquor in the circulation system.

Cost equation - The theoretical annual cost (G) of operation and maintenance for wet collectors can be expressed as follows:

$$G = S \left[0.7457\ HK \left(\frac{P}{6356E} + \frac{Qg}{1722F} + \frac{Qh}{3960F} \right) + WHL + M \right] \qquad (3)$$

where:

S = design capacity of the wet collector, acfm

0.7457 = a constant (1 horsepower = 0.7457 kilowatts)

H = annual operating time (assumed 8,760 hr.)

K = power costs, dollars/kilowatt-hr

P = pressure drop across fan, inches of water (see Table A-6)

Q = liquor circulation, gal/acfm (see Table A-6)

g = liquor pressure at the collector, psig (see Table A-6)

h = physical height liquor is pumped in circulation system, feet (see Table A-6)

W = make-up liquor consumption, gal/hr/acfm (see Table A-6)

L = liquor cost, dollars/gal (see Table A-6)

M = maintenance cost, dollars/acfm (see Table A-5)

E = fan efficiency, assumed to be 60% (expressed as 0.60)

F = pump efficiency, assumed to be 50% (expressed as 0.50)

The above equation can be simplified according to Semrau's total "contacting power" concept.[6] Semrau shows that efficiency is proportional to the total energy input to meet fan and nozzle power requirements. The scrubbing (contact) power factors in Table A-6 were calculated from typical performance data listed in manufacturers' brochures. These factors are in general agreement with data reported by Semrau. Using Semrau's concept the equation for operating cost can be simplified as follows:

$$G = S\left[0.7457\ HK\left(Z + \frac{Qh}{1980}\right) + WHL + M\right]$$

where Z = contact power (i.e., total power input required for collection efficiency), horsepower/acfm (see Table A-6). It is a combination of:

1. Fan horsepower/acfm $\left(= \frac{P}{6356E}\right)$, and
2. Pump horsepower/acfm $\left(= \frac{Qg}{1722F}\right.$ the power to atomize water through a nozzle$\left.\right)$

The pump horsepower, $Qh/1980$, required to provide pressure head is not included in the contact power requirements.

A 5.3.4 Electrostatic Precipitators: The only operating cost considered in the operation of electrostatic precipitators is the power cost for ionizing the gas and operating the fan. As the pressure drop across the equipment is usually less than 1/2 in. of water, the cost of operating the fan is assumed to be negligible. The power cost varies with the efficiency and the size of the equipment.

Maintenance usually requires the services of an engineer or highly trained operator, in addition to regular maintenance personnel. Maintenance includes servicing fans and replacing damaged wires and rectifiers.

Cost equation - The theoretical annual cost (G) for operation and maintenance of electrostatic precipitators is as follows:

$$G = S\left[JHK + M\right] \qquad (4)$$

where

S = design capacity of the electrostatic precipitator, acfm

J = power requirements, kilowatts/acfm (See Table A-6)

H = annual operating time (assumed 8,760 hr.)

K = power cost, dollars/kilowatt-hr (see Table A-6)

M = maintenance cost, dollars/acfm (see Table A-5)

A.5.3.5 Fabric Filters: Operating costs for fabric filters include power costs for operating the fan and the bag cleaning device. These costs vary directly with size of equipment and the pressure drop. Maintenance costs include costs for servicing the fan and shaking mechanism, emptying the hoppers, and replacing the worn bags.

Cost equation - The theoretical annual cost (G) for operation and maintenance of fabric filters is as follows:

$$G = S\left[\frac{0.7457}{6356E} PHK + M\right] \qquad (5)$$

where:

S = design capacity of the fabric filter, acfm

P = pressure drop, inches of water (see Table A-6)

E = fan efficiency, which is assumed to be 60% (expressed as 0.60)

0.7457 = a constant (1 horsepower = 0.7457 kilowatt)

H = annual operating time (assumed 8,760 hr.)

K = power cost, dollars per kilowatt-hr. (see Table A-6)

M = maintenance cost, dollars/acfm (see Table A-5)

For computational purposes, the cost formula can be simplified as follows:

$$G = S\left[195.5 \times 10^{-6}\ PHK + M\right] \qquad (6)$$

A.5.3.6 Afterburners: The major operating cost item for afterburners is fuel. Fuel requirements are a direct function of the gas volume, the enthalpy of the gas, and the difference between inlet and outlet gas temperatures. For most applications, the inlet gas temperature at the source ranges from 300° to 400°F. Outlet temperatures may vary from 1200° to 1500°F for direct flame afterburners and from 730° to 1200°F for catalytic afterburners.[2] The use of heat exchangers may bring about a 50% reduction in the temperature difference.[7,8] Table A-7 lists hourly fuel costs based on a natural-gas cost of $0.60/million Btu. No credit was given for heat of combustion of particulate or other matter. These costs were developed from enthalpies (heat content) of the process gas at given temperatures.[9] Maintenance includes servicing the fan, repairing the refractory lining, washing and rinsing the catalyst, and rejuvenating the catalyst.[10]

TABLE A-7

HOURLY FUEL COSTS

Device	Temperature, (°F)		Δ Temperature, (°F)	Fuel Cost,[a] Dollars/acfm-Hr
	Inlet	Outlet		
Direct flame (DF)	380	1400	1020	0.00057
DF with heat exchanger	1000	1400	400	0.00023
Catalytic afterburner (CAB)	380	900	520	0.00028
CAB with heat exchanger	650	900	250	0.00014

---

[a] These figures include the cost of heating an additional 50% excess air. It is assumed there is no heat content in the material or pollutant being consumed.

The equation for calculating the operation and maintenance costs (G) is as follows:

$$G = S\left[\frac{0.7457}{6356}\,\frac{PHK}{E} + HF + M\right] \qquad (7)$$

where:

S = design capacity of the afterburner, acfm

P = pressure drop, inches of water (see Table A-6)

E = fan efficiency, assumed to be 60% (expressed as 0.60)

0.7457 = a constant (1 horsepower = 0.7457 kilowatt)

H = annual operating time (assumed 8,760 hr.)

K = power cost, dollars per kilowatt-hour (see Table A-6)

F = fuel cost, dollars per acfm/hr (see Table A-7)

M = maintenance cost, dollars/acfm (see Table A-5)

For computational purposes, the cost formula is simplified as follows:

$$G = S \left[195.5 \times 10^{-6}\ PHK + HF + M \right] \qquad (8)$$

A.5.4 Capital Charges

Capital charge includes overhead expenses such as taxes, insurance, and interest incurred in the operation of a control device. Such costs frequently lose specific identity because of internal accounting practices. It is possible, however, by reasonable assumptions, to include capital charges in the annualized cost of control.

A.5.5 Annualization of Costs

Annualized capital costs are estimated by depreciating the capital investment (total installed cost) over the expected life of the control equipment and adding the capital charges (taxes, interest, and insurance). Adding the recurring maintenance and operation costs to this figure gives a total annualized cost of control. Total annualized cost estimates are shown in Section A.7.

A.5.6 Assumptions in Annualized Control Cost Elements

Annualized control costs will differ from installation to installation and from region to region, and certain simplifying assumptions have been necessary to develop the cost figures of this section. If more information for a given location is available, it is desirable to substitute this for the assumptions used here.

A.5.6.1 Annualized Capital Cost Assumptions: The simplifying assumptions for computing the total annualized capital cost are as follows:

1. Purchase and installation costs are depreciated over 15 years, a period assumed to be a feasible economic life for control devices.

2. The straight-line method of depreciation (6-2/3%/year) is used because it is the most common method used in accounting practices. This method has the simplicity of a constant annual writeoff.

3. Other costs called capital charges--which include interest, taxes, insurance, and other miscellaneous costs--are assumed to be equal to the amount of depreciation, or 6-2/3% of the initial capital cost of the control equipment installed. Therefore, depreciation plus these other annual charges amounts to 13-1/3% of the initial capital cost of the equipment.

A.5.6.2 Operating Cost Assumptions: The following assumptions were taken into account for computing operation and maintenance costs.

1. Power costs included in annual operating expense reflect electricity used by all systems directly associated with the control equipment. Electrical power requirements are computed on a constant usage basis at a specified gas volume.

2. For wet collectors, it is assumed that the liquor is recirculated in a closed system. Liquor consumption consists of the makeup liquor which must be added from time to time. Stack gas temperature influences the rate of liquor loss; this influence is partially accounted for by assuming a constant loss per cubic foot of stack gas volume. This assumption is necessary because of the extremely wide range of stack gas temperatures.

3. The costs for electricity and water are computed on the marginal rate classes for each size user, which assumes that any additional consumption will be priced at the lowest rate-highest volume class available. Except where specifically indicated, the typical values for the pressure drop and cost of electricity (see Table A-7) were assumed in all control cost calculations and illustrations.

4. The disposal cost and/or recovered value of collected effluents are not included in the operating cost calculations because of cost differences from process to process. Disposal cost figures for several major industrial categories are reported in Section A.8.

A.5.6.3 Maintenance Cost Assumption: It is assumed that a user of control equipment establishes a preventive (scheduled) maintenance program and carries it out to maintain equipment at its designed collection efficiency. Further, it is assumed that unscheduled maintenance, such as replacement of defective parts, is undertaken as required. The cost incurred for equipment modification or repair due to an operational accident is not included.

A.6 METHOD FOR ESTIMATING ANNUAL COST OF CONTROL FOR A SPECIFIC SOURCE

A.6.1 General

As previously indicated, it is beyond the scope of this Appendix to identify and assess the cost of control for a specific source. Such assessments can, however, be calculated by applying the steps outlined below.

A.6.2 Procedure

The following procedure can be used to determine the expected cost of control for any source.

Step 1. Describe the source (including characteristics of the process), the characteristics and consumption of fuel for combustion, and the total number of hours in operation annually. Emissions can be determined by making stack gas tests or can be estimated by making calculations using the emission factors.

Step 2. Select the applicable types of control equipment. Figure A-1 illustrates what must be considered in selecting the optimum type of control equipment.

Step 3. Specify pressure drops, efficiencies, construction material, energy and fuel requirements, and size limitations for the selected control equipment, taking into account any existing equipment.

Step 4. Determine the gas flow in acfm at the point of collector location. For wet collectors, this would be the water saturated gas volume. This should be done by taking measurements at maximum operating conditions.

Step 5. Determine the estimated total purchase cost for the specific selected device (curves found in Section A.7) at the required gas volume and control efficiency. For fabric filters, select the proper filter medium for the process.

Step 6. Multiply the cost found in Step 5 by the low, typical, and high installation cost factors (Table A-3), and add the result to the estimated total purchase cost to obtain the corresponding low, typical, and high total installed costs. Conditions affecting the cost of installation are listed in Table A-4.

Step 7. Calculate the total annual capital cost as follows:

$$\begin{aligned}\text{Annualized capital cost} &= \text{depreciation} + \text{capital charges}\\ &= 0.133 \times \text{total investment cost*}\end{aligned}$$

Step 8. Compute the cost of electricity, maintenance, and liquor consumption.

Step 9. Compute low, medium, and high operating and maintenance costs from the appropriate formulas:

Dry centrifugal collectors

$$G = S\left[195.5 \times 10^{-6}\ PHK + M\right]$$

---

* Based on the assumptions in Section A.5.6.1.

Wet scrubbers

$$G = S\left[0.7457\ HK\left(Z + \frac{Qh}{1980}\right) + WHL + M\right]$$

Electrostatic precipitator

$$G = S\left[JHK + M\right]$$

Fabric filters

$$G = S\left[195.5 \times 10^{-6}\ PHK + M\right]$$

Afterburners

$$G = S\left[195.5 \times 10^{-6}\ PHK + M + HF\right]$$

where:

G = theoretical value for operating and maintenance costs

S = the design capacity of the collection device, acfm

P = pressure drop of the gas, inches of water

H = annual operating time

K = power costs, dollars per kilowatt-hour

Q = liquor circulation, gal/acfm

h = physical height that liquor is pumped in circulation system, feet

Z = total power input required for scrubbing efficiency, horsepower/acfm

M = maintenance cost, dollars/acfm

W = liquor consumption, gal/hr/acfm

L = cost of liquor, dollars/gal

J = power requirement, kilowatts/acfm based on efficiency

F = fuel cost, dollars/hr/acfm

Step 10. Add the typical annualized capital cost to the typical operating and maintenance cost to yield the estimated total annualized cost of control.

Step 11. Because the above calculation is a point estimate, the range of costs should be investigated. For this, a variance is calculated and applied to the total estimated annual cost. The low cost variance (V_l) and high cost variance (V_h) of an equipment combination can be computed by using the square root of the sum of the squares. The formulas for these variances are as follows:

$$V_l = \sqrt{(C_m - C_l)^2 + (G_m - G_l)^2}$$

$$V_h = \sqrt{(C_h - C_m)^2 + (G_h - G_m)^2}$$

where:

C_l, C_m, and C_h are the low, typical, and high annual capital cost estimates, respectively, and G_l, G_m, and G_h are the low, typical, and high operation and maintenance cost estimates. These formulas are taken from the usual definition of the standard error of a linear combination of statistically independent variables. They permit computation of the most probable, rather than the extreme, range of costs.

Step 12. The high cost variance (V_h) is added to the total estimated annual cost to yield the high cost limit.

Step 13. The low cost variance (V_l) is subtracted from this total estimated annual cost to yield the low cost limit.

A.6.3 Sample Calculations

The following calculations illustrate the method used to determine the total estimated annual cost of control. The following example shows the estimation of annualized cost for a 60,000 cfm, 90% (medium efficiency) wet collector.

Step 1. Annual operating time = 8,760 hr. (H)

Step 2. Wet collector (given)

Step 3. 90% efficiency (given)

Scrubbing power required - 0.0035 horsepower/acfm (Z)

Step 4. Actual gas flow = 60,000 acfm (given)

Step 5. Purchase cost = $17,000 (from Section A.7.4 for wet collectors)

Step 6. Installation factors from Table A-3 are 50%, 100%, and 200%

Installation factor	50%	100%	200%
Installation cost	8,500	17,000	34,000
Purchase cost	17,000	17,000	17,000
Total capital cost	$25,500	$34,000	$51,000

Step 7. 0.133 x [Total capital cost] = annual capital cost (C)

C_l = 0.133 x $25,500 = $3,400

C_m = 0.133 x $34,000 = $4,530

C_h = 0.133 x $51,000 = $6,800

Step 8. Power cost, dollars/kilowatt-hr (K)

Low	Typical	High
0.005	0.011	0.020

Maintenance cost, dollars/acfm (M)

Low	Typical	High
0.02	0.04	0.06

Liquor cost, 10^{-3} dollars/gal (L)

Low	Typical	High
0.35	0.50	1.00

Heat required for circulation in system, feet (h)

Low	Typical	High
1	30	60

Liquor circulation, gallons/acfm (Q)

Low	Typical	High
0.001	0.008	0.020

Makeup liquor rate, 10^{-3} gal/hr/acfm, (W) = 0.5

Step 9. Using the following formula to determine annual operating cost (G)

$$G = S\left[\left(Z + \frac{Qh}{1980}\right)(0.7457\ HK) + WHL + M\right]$$

The low, typical, and high operating and maintenance costs are as follows:

G_l = \$8,200 G_m = \$18,100 G_h = \$35,900

Step 10. From the steps 7 and 9,

C_m = \$4,530 G_m = \$18,100

Then, the total estimated annual cost is as follows:

$C_m + G_m$ = \$22,600

Step 11. Using the square root of the sum of the squares of the differences, the high and low cost variances are as follows:

$$V_l = \sqrt{(C_m - C_l)^2 + (G_m - G_l)^2}$$

$$V_l = \sqrt{(4{,}530 - 3{,}400)^2 + (18{,}100 - 8{,}200)^2}$$

V_l = \$10,000

$$V_h = \sqrt{(C_h - C_m)^2 + (G_h - G_m)^2}$$

$$V_h = \sqrt{(6{,}800 - 4{,}530)^2 + (35{,}900 - 18{,}100)^2}$$

V_h = \$17,900

Step 12. From Step 10, the total estimated annual cost = \$22,600

From Step 11, V_l = \$10,000

Low cost limit = \$22,600 - \$10,000 = \$12,600

Step 13. Total estimated annual cost = \$22,600

From Step 11, V_h = \$17,900

High cost limit = \$22,600 + \$17,900 = \$40,500

Step 14. The amount of particulate matter emitted may be calculated if the inlet conditions are known.

A.6.4 Annualized Cost Variation

The previous section illustrated the probable high and low cost limits for a single installation, taking into account the variation in costs for installation, maintenance, and operation. To compute the annualized cost for a given emission reduction system, one must take into account four variables: (1) collection efficiency of the system, (2) cost of installing the system, (3) cost of operation, and (4) maintenance cost. A more complete summary of the range of total annualized costs is shown in Table A-8 for a 60,000 acfm wet collector. This table illustrates cost figures for 81 possible combinations of each of the four variables, with each variable taking on three independent values--low, typical, and high. It is constructed by the procedure outlined in Steps 1 through 10 in the previous section. The constants for computing these values are taken from Tables A-5 and A-6. Table A-8 shows that a low-efficiency 60,000 acfm wet collector with low installation, maintenance, and operation costs will cost approximately \$6,100/ year to operate (extreme upper left-hand corner). The most efficient (99% efficiency) wet collector, according to the table, will cost as high as \$137,400/yr to operate. The most likely costs for efficiencies of 75%, 90%, and 99% are \$11,300, \$22,700, and \$74,500, respectively. The type of data shown in Table A-8 is useful in developing cost-effectiveness relationships. Note that this table does not show the variances, V_l and V_h; these should be used only when the probable cost limits are desired.

TABLE A-8

ILLUSTRATIVE PRESENTATION OF ANNUAL COSTS OF CONTROL FOR 60,000 ACFM WET SCRUBBER (DOLLARS)

		E_l = 75%[a,b]			E_m = 90%			E_h = 99%		
e/	d/	I_l[c]	I_m	I_h	I_l	I_m	I_h	I_l	I_m	I_h
O_l	M_l	6,100	6,800	8,100	11,800	13,000	15,200	35,500	37,800	42,300
	M_m	7,300	8,000	9,300	13,000	14,200	16,400	36,700	39,000	43,500
	M_h	8,500	9,200	10,500	14,200	15,400	17,600	37,900	40,200	44,700
O_m	M_l	9,500	10,100	11,500	20,300	21,500	23,700	71,100	73,300	77,900
	M_m	10,700	11,300	12,700	21,500	22,700	24,900	72,300	74,500	79,100
	M_h	11,900	12,500	13,900	22,700	23,900	26,100	73,500	75,700	80,300
O_h	M_l	18,300	18,900	20,300	36,900	38,100	40,300	128,200	130,500	135,000
	M_m	19,500	20,100	21,500	38,100	39,300	41,500	129,400	131,700	136,200
	M_h	20,700	21,300	22,700	39,300	40,500	42,700	130,600	132,900	137,400

---

a/ E = efficiency factor.

b/ Subscripts l, m, and h indicate low, medium, and high ranges, respectively.

c/ I = installation factor.

d/ M = maintenance factor.

e/ O = operating factor.

Note: A similar table can be generated to show the various control costs for any type of control equipment by specifying operating conditions and calculating each entry. This procedure provides complete information to aid in the assessment of existing controls or other control alternatives.

A.7 COST CURVES BY EQUIPMENT TYPE

A.7.1 General

The following sections contain a series of control cost curves (see Figures A-5 through A-24). For each type of control equipment, a series of curves is presented: (1) purchase cost curves, (2) installed cost curves, and (3) annualized cost curves.

The estimated purchase cost curves show the dollar amounts charged by manufacturers for basic control equipment, exclusive of transportation charges to the installation site. This basic control equipment includes built-in auxiliary parts of the control unit, such as instrumentation and solution pumps. The installed cost curves include the purchase costs, additional auxiliary equipment costs, and installation costs, as described in Section A.5.2. The annualized cost curves include elements discussed in Sections A.5.3 through A.5.6. The assumptions, sources of data, and the limitations used to develop this information are discussed in Sections A.3 and A.4.

A.7.2 Gravitational Collectors

In computing the cost of gravity collectors, three collection efficiencies were considered. These efficiencies were based on the assumption of essentially complete removal of 87-μ, 50-μ, and 25-μ particles, and are designated as low, medium, and high efficiencies, respectively. The low and medium efficiency collectors are simple expansion chambers, and the high efficiency collector is a multiple-tray settling chamber, commonly called a Howard separator.

In actual operation, the collection efficiency for a gravitational collector depends on the particle size distribution. In cleaning the flue gas from a stoker-fired coal furnace, for example, low-, medium-, and high-efficiency collectors would have particle removal efficiencies of approximately 64%, 75%, and 88%, respectively. In cleaning the flue gas from a pulverized-coal furnace, these same collectors, because of the smaller sized particles emitted by the combustion unit, would have approximate efficiencies of 21%, 34%, and 56%, respectively.

The purchase costs of gravitational collectors are shown for three different efficiencies in Figure A-5. These are approximate costs for typical installations. If it were necessary to include insulation or a corrosion-resistant lining, the costs would be higher. The total installed cost was also calculated for each efficiency and is shown in Figure A-6. The total installed cost is the sum of the purchase and installation costs.

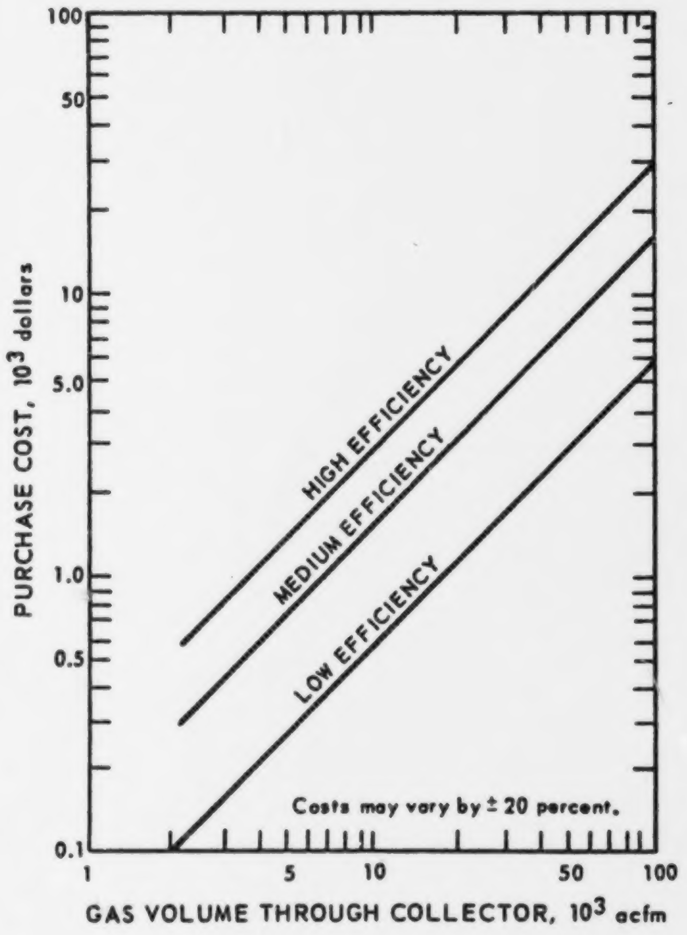


Figure A-5 - Purchase Cost of Gravitational Collectors

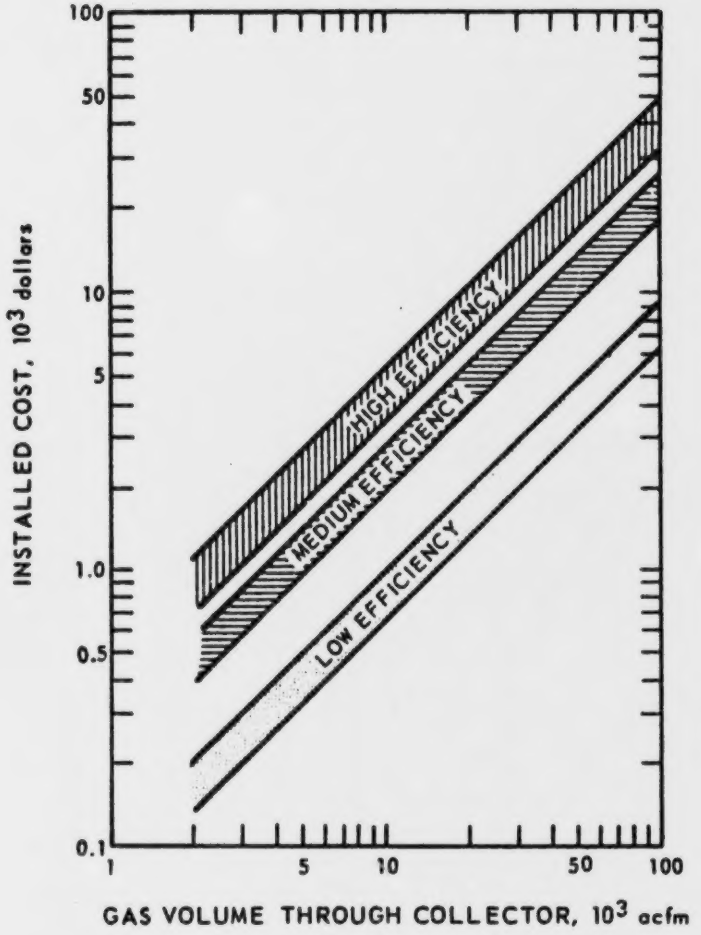
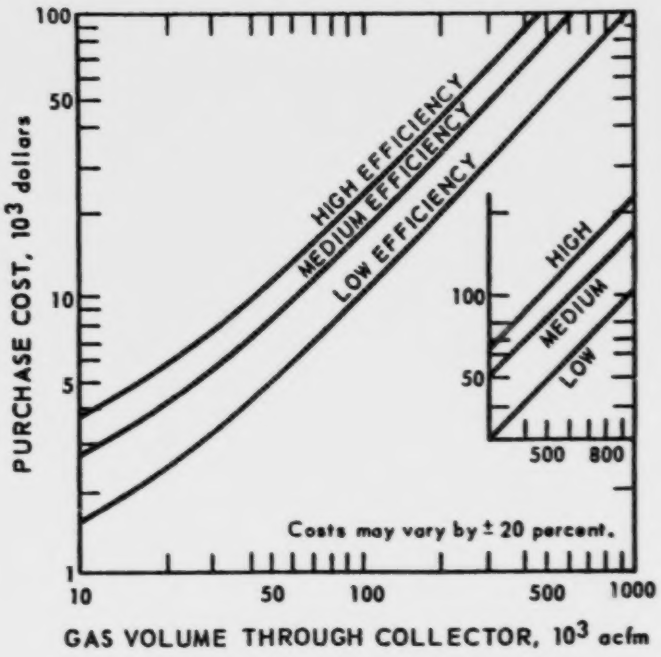


Figure A-6 - Installed Cost of Gravitational Collectors



Costs may vary by ± 20 percent.

Figure A-7 - Purchase Cost of Dry Centrifugal Collectors

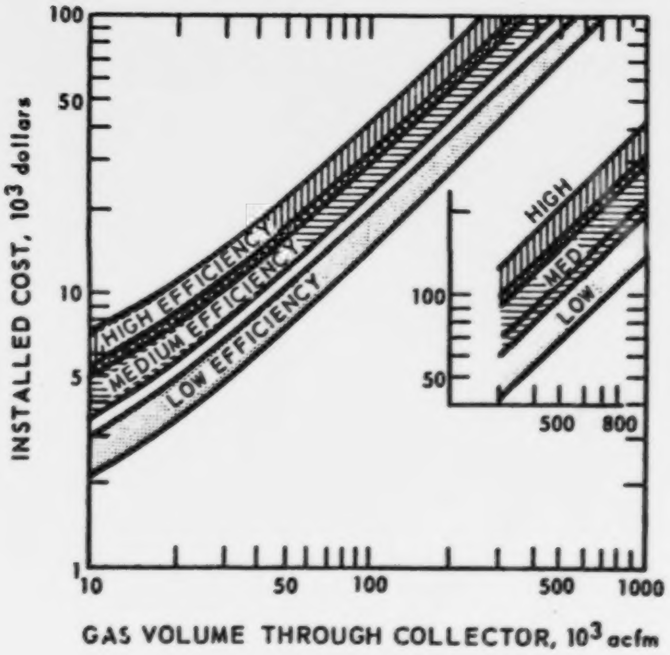


Figure A-8 - Installed Cost of Dry Centrifugal Collectors

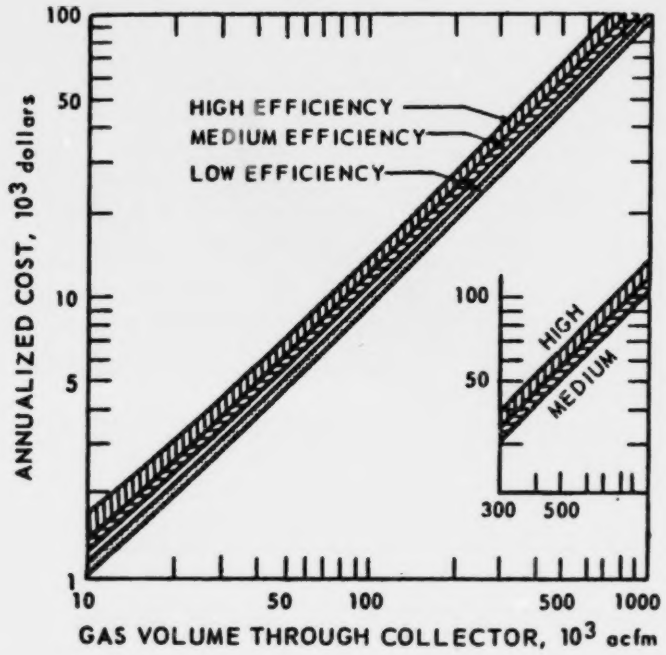


Figure A-9 - Annualized Cost of Operation of Dry Centrifugal Collectors

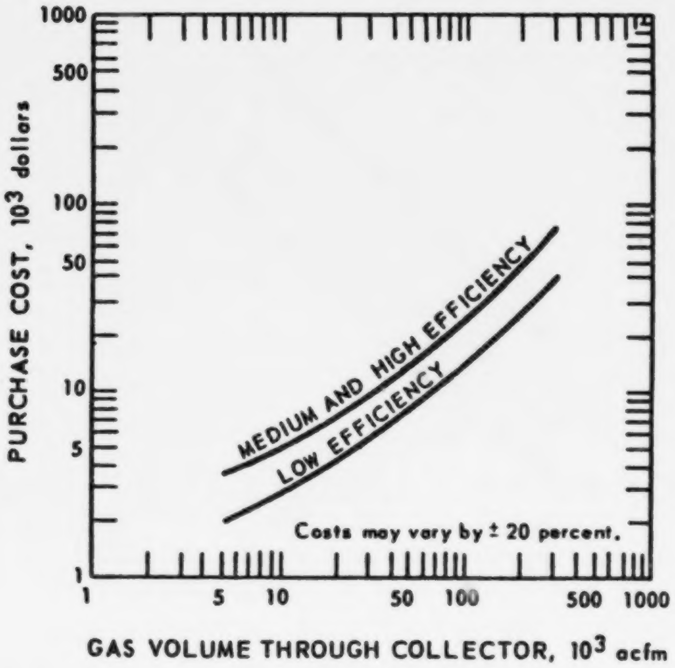


Figure A-10 - Purchase Cost of Wet Collectors

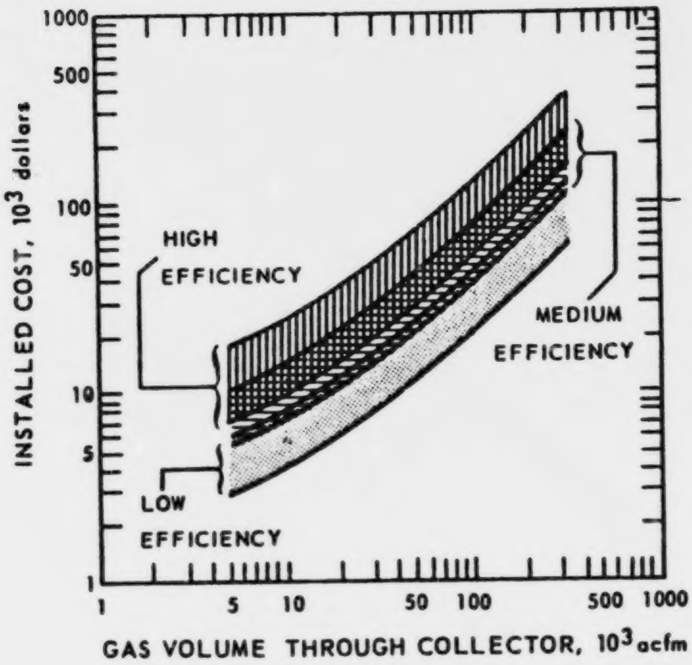


Figure A-11 - Installed Cost of Wet Collectors

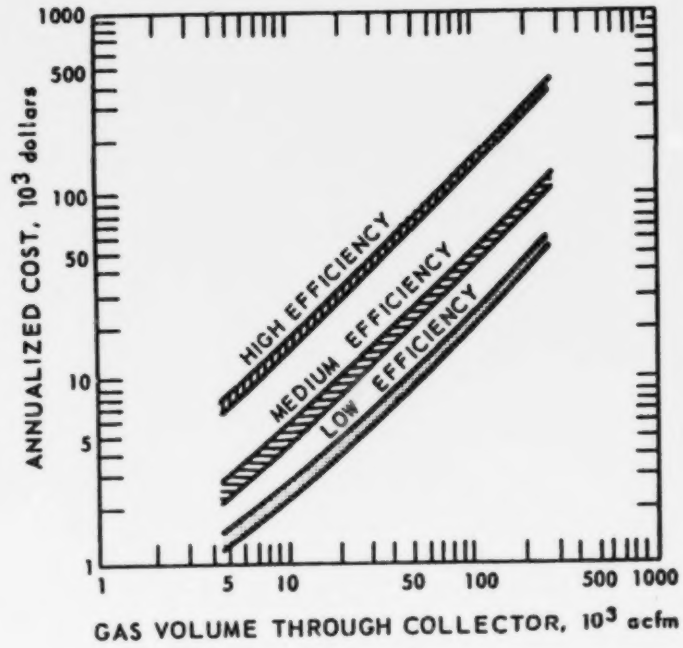


Figure A-12 - Annualized Cost of Operation of Wet Collectors

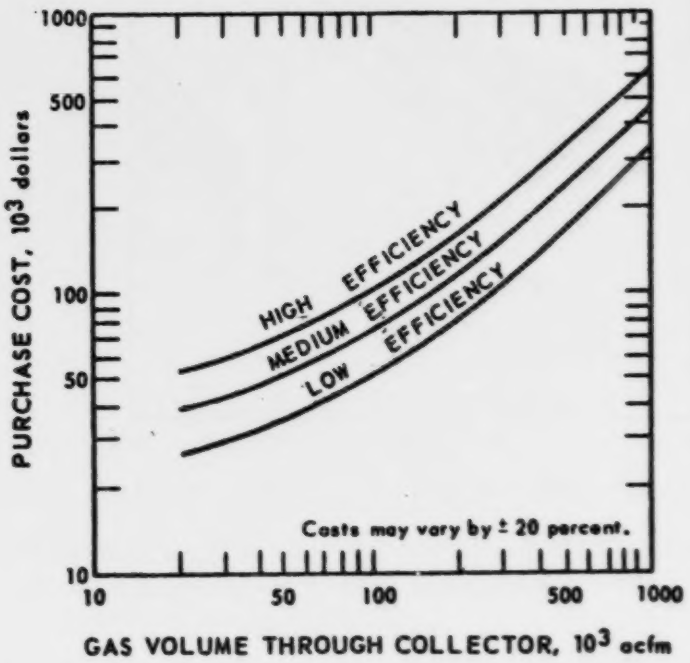


Figure A-13 - Purchase Cost of High-Voltage Electrostatic Precipitators

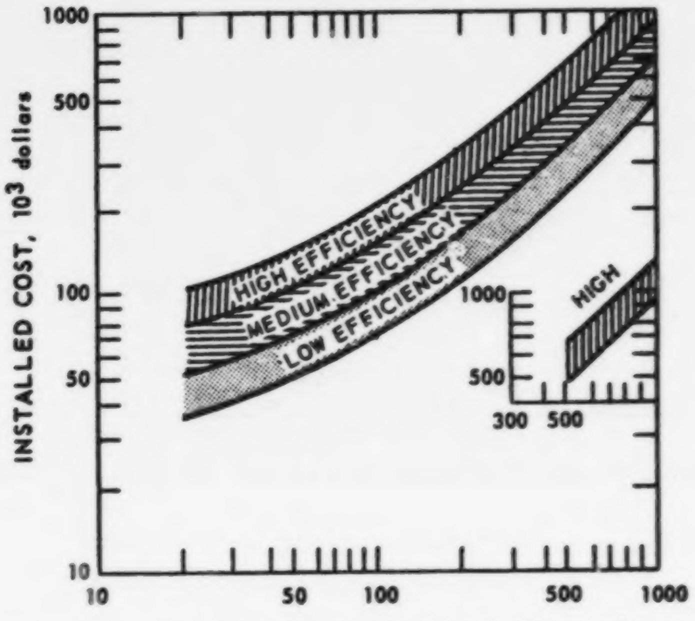


Figure A-14 - Installed Cost of High-Voltage Electrostatic Precipitators

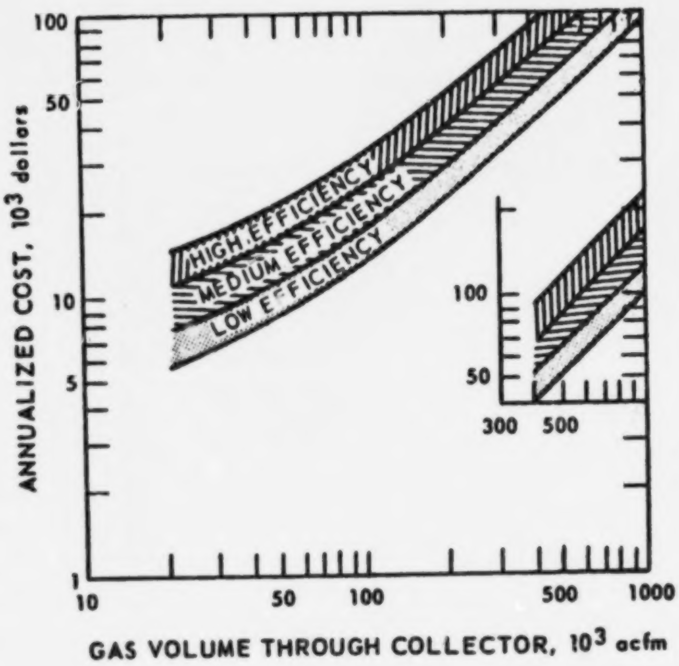


Figure A-15 - Annualized Cost of Operation of High-Voltage Electrostatic Precipitators

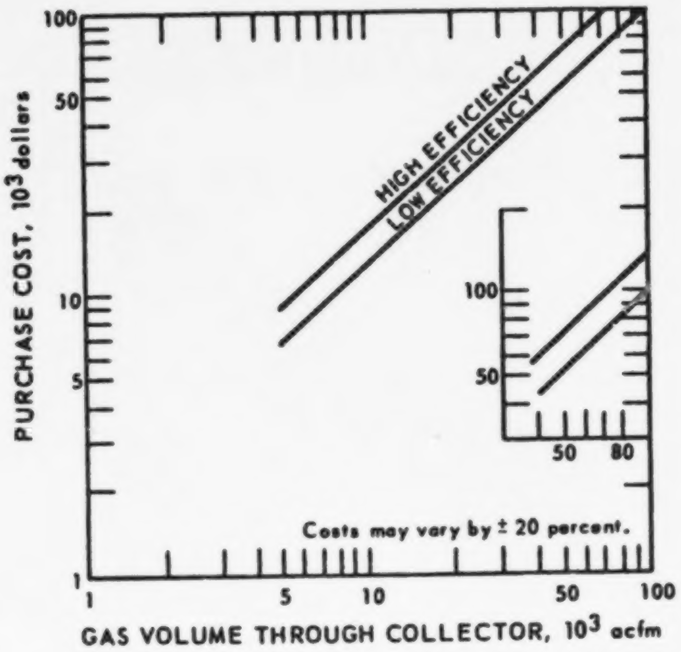


Figure A-16 - Purchase Cost of Low-Voltage Electrostatic Precipitators

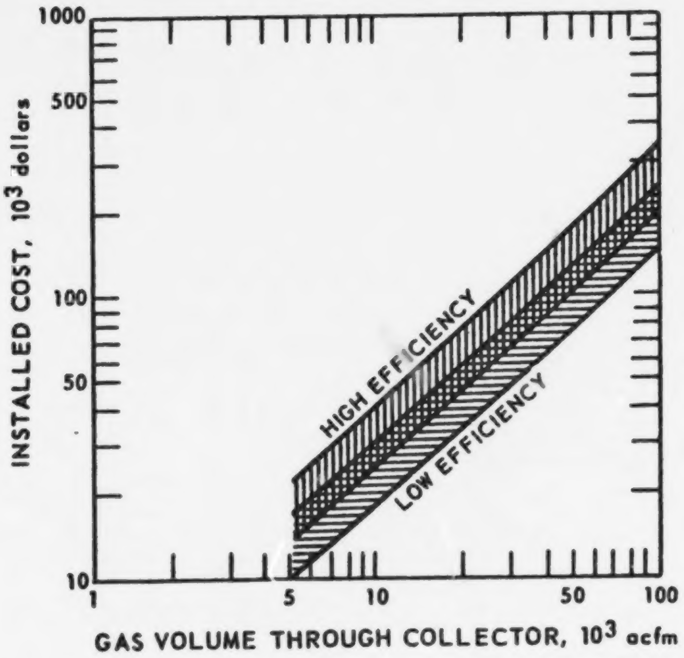


Figure A-17 - Installed Cost of Low-Voltage Electrostatic Precipitators

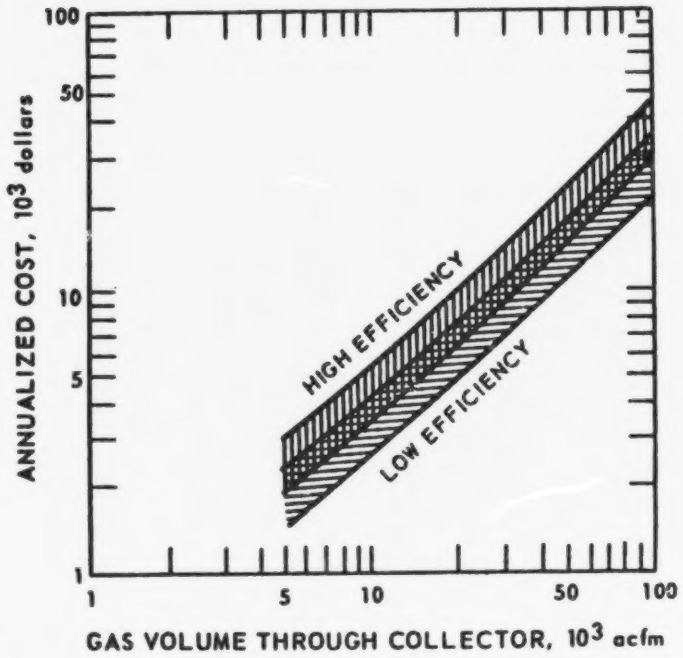


Figure A-18 - Annualized Cost of Operation of Low-Voltage Electrostatic Precipitators

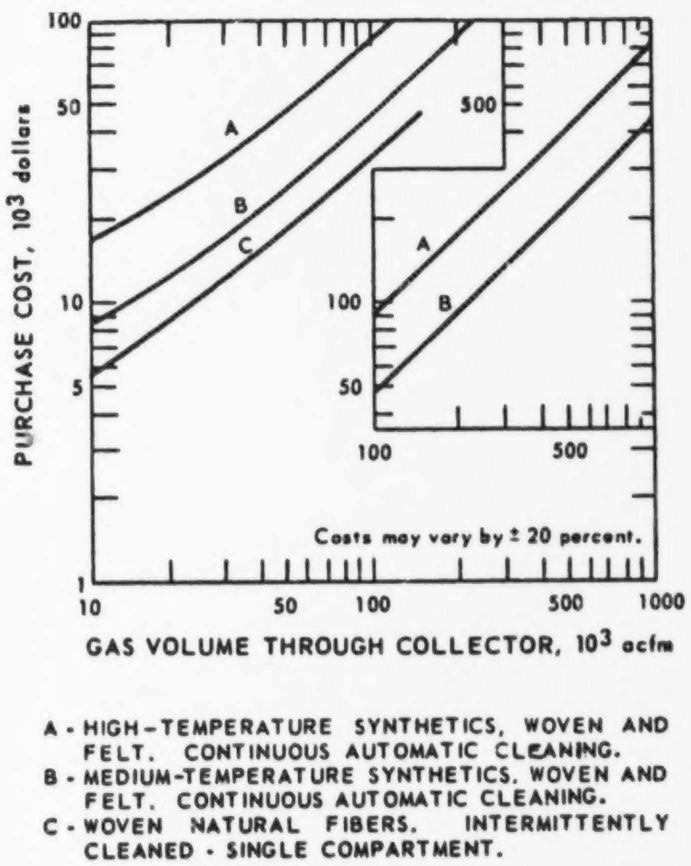


Figure A-19 - Purchase Cost of Fabric Filters

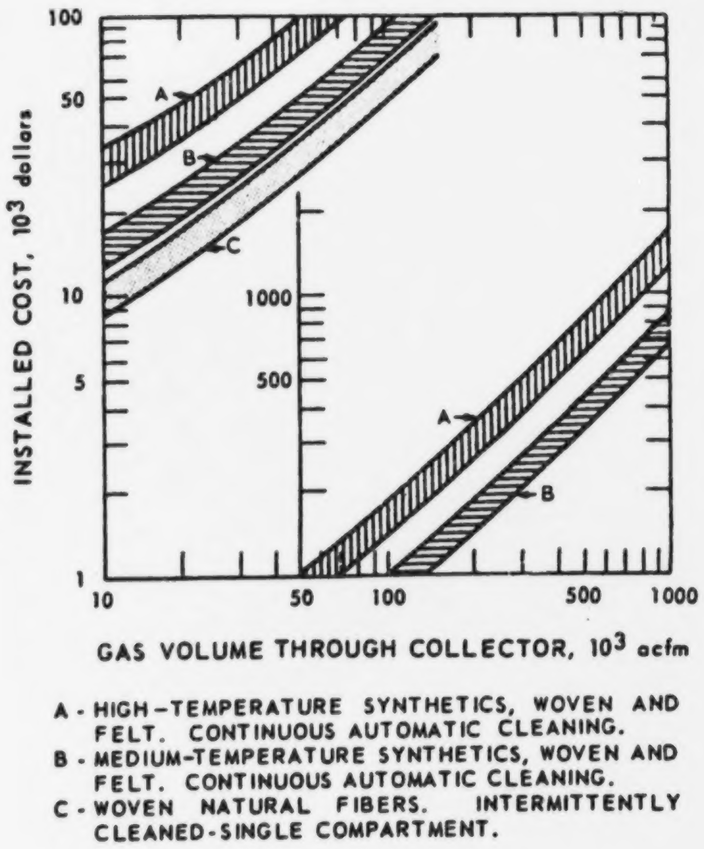


Figure A-20 - Installed Cost of Fabric Filters

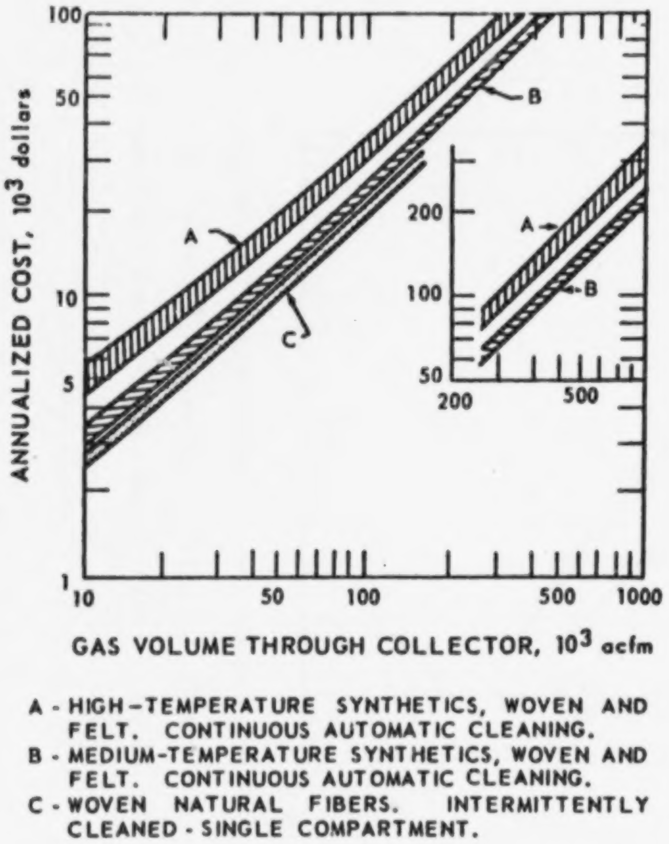


Figure A-21 - Annualized Cost of Operation of Fabric Filters

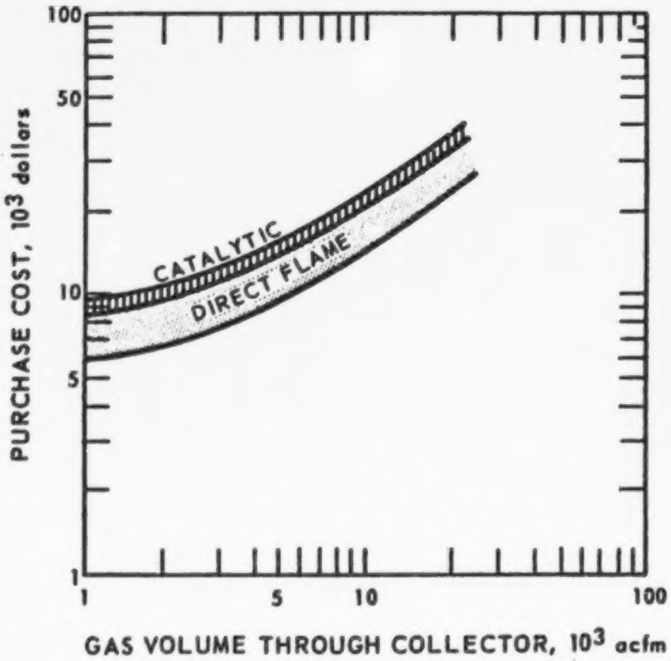


Figure A-22 - Purchase Cost of Afterburners

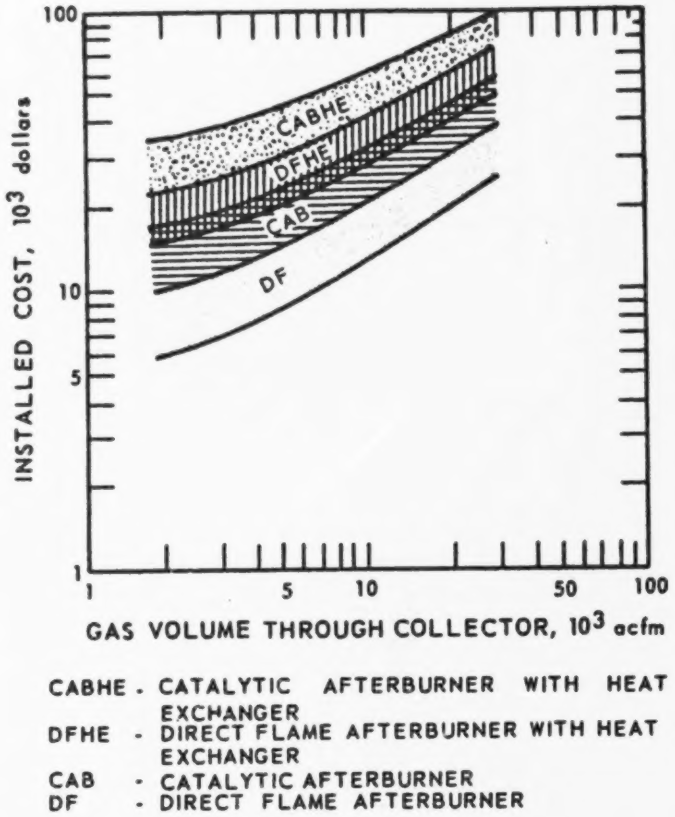


Figure A-23 - Installed Cost of Afterburners

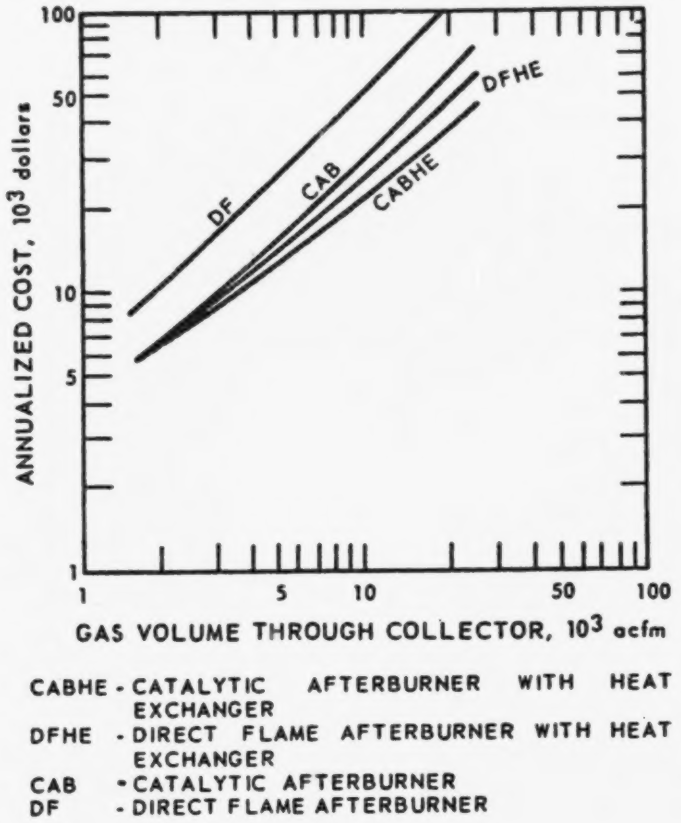


Figure A-24 - Annualized Cost of Operation of Afterburners

The installation costs were assumed to range from 33% to 100% of the purchase cost (see Table A-3), and this range results in a cost band for each efficiency, as shown in the figure. No annualized cost curves are presented for these collectors because operation and maintenance costs, other than for removal and disposal of collected material, usually are negligible, except where corrosion may be a problem. Section A.8 provides specific information on the disposal of collected material.

A.7.3 Dry Centrifugal Collectors

The costs of purchasing, installing, and operating mechanical centrifugal collectors are given in Figures A-7, A-8, and A-9, respectively. The curves in these figures show costs for collectors that operate at nominal efficiencies of 50%, 70%, and 95% (see Section A.4). Costs are plotted for equipment sizes ranging from 10,000 to 1,000,000 acfm. The assumptions used in calculating annual operation and maintenance costs for dry centrifugal collectors are as follows:

1. Annual operating time = 8,760 hr.
2. Collector pressure drop = 3 in. of water
3. Power cost = $0.011/kilowatt-hr
4. Maintenance cost = $0.015/acfm

A.7.4 Wet Collectors

The costs of purchasing, installing, and operating wet collectors are given in Figures A-10, A-11, and A-12, respectively, as a function of equipment size. The curves in these figures show costs for collectors that operate at nominal efficiencies of 75%, 90%, and 99% (see Section A.4). The basic hardware costs for medium and high collection-efficiency equipment are reported by manufacturers to lie in the same cost range and both appear on the same curve in Figure A-10. The higher installed cost of a high collection-efficiency system in Figure A-11 results from the need for larger, more expensive auxiliary equipment (based on Table A-3). The assumptions used in calculating annual operating and maintenance costs for wet collectors are as follows:

1. Annual operating time = 8,760 hr.
2. Contact power requirements:

   0.0013 horsepower/acfm for 75% efficiency

   0.0035 horsepower/acfm for 90% efficiency

   0.015 horsepower/acfm for 99% efficiency

3. Power cost = \$0.011/kilowatt-hr

4. Maintenance cost = \$0.04/acfm

5. Head required for liquor circulation in collection system = 30 ft.

6. Liquor circulation = 0.008 gal/acfm

7. Liquor consumption = 0.0005 gal/hr-acfm

8. Liquor cost = \$0.0005/gal

A.7.5 High-Voltage Electrostatic Precipitators

The costs of purchasing, installing, and operating high-voltage electrostatic precipitators are given in Figures A-13, A-14, and A-15, respectively. The curves in these figures show costs for collectors that operate at nominal efficiencies of 90%, 95%, and 99.5%. These costs are plotted for equipment sizes ranging from 20,000 to 1,000,000 acfm. The assumptions used in calculating annual operation and maintenance costs for high-voltage electrostatic precipitators are as follows:

1. Annual operating time = 8,760 hr.

2. Electrical power requirements:

    0.00019 kilowatt/acfm for low efficiency

    0.00026 kilowatt/acfm for medium efficiency

    0.00034 kilowatt/acfm for high efficiency

3. Power cost = \$0.011/kilowatt-hr

4. Maintenance cost = \$0.02/acfm

A.7.6 Low-Voltage Electrostatic Precipitators

The curves in Figures A-16, A-17, and A-18 indicate purchase cost, installed cost, and operation cost of low-voltage electrostatic precipitators for low and high collection efficiencies based on design gas velocities of 150 and 125 ft/min, respectively. Packaged modular low-voltage precipitators with flow rates of less than 1,500 acfm are used to collect oil mist from machining operations. Purchase cost of such a unit usually is less than \$1,200. The assumptions used in calculating annual operation and maintenance costs for low-voltage electrostatic precipitators are as follows:

1. Annual operating time = 8,760 hr.

2. Electrical power requirements:

   0.000015 kilowatt/acfm for low efficiency

   0.000040 kilowatt/acfm for high efficiency

3. Power cost = $0.011/kilowatt-hr

4. Maintenance cost = $0.02/acfm

A.7.7 Fabric Filters

Figures A-19, A-20, and A-21 show purchase cost, installed cost, and annualized cost of control for three different types of filters. Each of the three filters is designed with about the same efficiency--99.9%. Costs are plotted for equipment sizes ranging from 10,000 to 1,000,000 acfm.

The control costs curves represent the following different types of filter installations:

1. Curve A represents a fabric filter installation with high-temperature synthetic woven fibers (including fiberglass) and felted fibers cleaned continuously and automatically.

2. Curve B represents an installation using medium-temperature synthetic woven and felted fibers, such as Orlon or Dacron, cleaned continuously and automatically.

3. Curve C is the least expensive installation. Woven natural fibers are used in a single compartment. Filters are intermittently cleaned. This equipment is rarely designed for processes handling over 150,000 acfm.

These control cost curves do not include data for furnace hoods, ventilation ductwork and precoolers that may appear only in certain installations. The assumptions for calculating operating and maintenance costs are as follows:

1. Annual operating time = 8,760 hr.

2. Pressure drop of the gas through the three types of fabric filters = 4 in. of water

3. Power cost = $0.05/acfm

4. Maintenance cost = $0.05/acfm

A.7.8 Afterburners

Afterburners are separated into four categories: (1) direct flame, (2) catalytic, (3) direct flame with heat recovery, and (4) catalytic with heat recovery. Equipment and installation costs were obtained from both the literature and manufacturers of afterburners. Sufficient data were received on catalytic afterburners to define the narrow purchase cost range shown in Figure A-22. The figure shows that purchase costs of direct flame afterburners have a wider range than those of catalytic afterburners.

Figure A-23 shows the installation costs for afterburners. Heat exchangers are considered accessory equipment and appear as part of the installation cost. Installation costs may range from 10% to 100% of the purchase costs, although in some situations they may be as high as 400%. Differences in installation costs are due to the differences in burner locations relative to the emission source, and differences in structural supports, ductwork, and foundations. Installation costs for the addition of equipment to existing plant facilities will be higher than similar costs for new plants. Other factors accounting for different installation fees are the degree of instrumentation required, engineering fees in manufacturers' bids, startup tests and adjustments, heat exchangers, auxiliary fans, and utilities. The assumptions for calculating operation and maintenance costs are as follows:

1. Annual operating time = 8,760 hr.

2. Fuel cost:

$0.57/1,000 acfm-hr for direct flame afterburner with no heat recovery

$0.23/1,000 acfm-hr for direct flame afterburner with heat recovery

$0.28/1,000 acfm-hr for catalytic afterburner with no heat recovery

$0.14/1,000 acfm-hr for catalytic afterburner with heat recovery

3. Maintenance cost:

$0.06/acfm for direct flame afterburner

$0.20/acfm for catalytic afterburner

4. Pressure drop through all afterburner types = 1 in. of water

5. Power cost = $0.011/kilowatt-hr

Cost comparisons presented in Figure A-24 show that the direct flame afterburner without a heat exchanger is the most expensive. The lower curve in Figure A-24 shows that the annualized cost of a direct flame afterburner with heat recovery is lower than the cost of a catalytic afterburner without heat recovery.

A.8 DISPOSAL OF COLLECTED PARTICULATE EMISSIONS

A.8.1 General

The installation of any pollution control system designed to collect particulate matter demands a decision regarding the disposal of the collected particulate material. This section discusses the relevant factors and illustrates the economic consequences of disposal of the collected material.

In the past, pollution control equipment often was installed either to reduce a severe nuisance or to recover valuable material. Such equipment not only prevented valuable material from escaping to the atmosphere, but also reduced costly cleaning of the plant grounds and facilities.

As industrial plants become more crowded together and as the public desires a higher quality of air, more emphasis will be placed on intensive control activities. This emphasis will increase the demand for more effective air pollution control. Generally, most air pollution control systems collect material that has little economic worth.

Basically, the alternatives for handling collected particulate material are as follows:

1. Return the material to the process.

2. Sell the material directly as collected.

3. Convert the material to a salable product.

4. Discard the material in the most economical manner.

The process of selecting an alternative should take into account the following questions:

1. Can the material be used within the company?

2. Is there a profitable market for the material?

3. What is the most economical method of disposal?

4. Is there land available for a landfill?

5. Is there a source of water available for:

    a. A wet pipeline system

    b. Disposal at sea

    c. Transportation by barge

6. Is there space available for a settling basin or filtering system?

7. Is there process-related equipment presently available for transporting or treating the collected material?

8. Is there access to a municipal waste treatment system?

9. Can technology and/or markets be developed for utilization of the waste material?

A.8.2 Elements of Disposal Systems

After examining feasible solutions to the disposal problem, the least costly alternative that is most compatible with other operating factors in the plant should be chosen. The decision should result from consideration of each of the four functional elements of the disposal system described below and their relationships to the manufacturing process.

1. Temporary storage, which allows gathering sufficient quantities of the collected material to make final disposal more economical. The unit cost of disposal usually is lower for greater quantities. Temporary storage may be convenient at many points in the overall disposal scheme, such as in the hopper or settling chamber of a pollution control device, or in a silo some distance from the plant.

2. Transportation that moves the collected material from the particulate control device to some location where disposal is relatively economical. In most cases, transportation displaces the material to a location where accumulation minimizes any potential interference with plant activities. Any single disposal system may require more than one method of

transporting the material. For example, a conveyor system may be used at the control device, a truck may be used to transport the material to a landfill area, and a bulldozer may be used to push it to its final disposal location.

3. Treatment that changes physical and/or chemical characteristics for easier disposal. Such treatment may simplify operations and reduce costs for handling and disposal of wastes. Frequently, for easier transport, particulate matter is made into a slurry by adding water to it. This permits the use of a pipeline, which is often the most economical method for transporting wastes over long distances. Slurries from wet-scrubbing pollution control systems frequently are treated in an opposite manner: the water is removed and the particulate matter is concentrated by filtration or sedimentation. This permits the ultimate disposal of a solid waste, rather than a sludge or a slurry. The method of treatment should be selected with a view to minimizing contamination of the environment. Examples of such treatment methods are the wetting of fine dust to prevent air pollution, the neutralization and filtration of slurries to prevent contamination of receiving waters, and the proper burial of solid material in a sanitary landfill.

4. Final disposition, which pertains to discarding the unusable material. Material which cannot be sold, converted, or reused ultimately can be discarded in landfills; or sometimes it can be disposed of in lagoons or the sea.

The following list shows some examples of the four functional elements for both wet and dry disposal systems.

A. Storage

  (1) Slurry of suspended particulate matter in water

    (a) Settling basin

    (b) Lagoon

    (c) Tank

  (2) Dry collected particulates

    (a) Mound

    (b) Rail car

    (c) Bin

    (d) Silo

B. Transportation

- (1) Slurry of suspended particulates in water
    - (a) Barge
    - (b) Pipeline
    - (c) Truck
    - (d) Rail
- (2) Dry collected particulates
    - (a) Truck
    - (b) Rail
    - (c) Front-end loader
    - (d) Conveying system
    - (e) Barge

C. Treatment

- (1) Slurry of suspended particulate in water[11]
    - (a) Sedimentation
    - (b) Filtration
    - (c) Flotation
    - (d) Thickening; wet combustion
    - (e) Lagoons and drying beds
    - (f) Vacuum filtration
    - (g) Centrifugation; incineration
    - (h) Neutralization

(2) Dry collected material

(a) Compressing

(b) Wetting

D. Final Disposition

(1) Landfill

(a) Public or private disposal sites

(b) Quarry

(c) Evacuated coal mine

(2) Lagoon

(3) Dump at sea

The arrangement of these elements in an overall disposal scheme is shown in Figure A-25. This flow diagram shows the movement of the collected material through various stages toward final disposal.

Environmental factors such as space, utilities, disposal facilities, and the desired form of collected waste material usually have an important bearing on the selection of a disposal system compatible with a specific type of particulate pollution control equipment. Therefore, a specific type of particulate pollution control equipment may not always call for the same waste disposal system.

A.8.3 Disposal Cost for Discarded Material

Table A-9 describes various disposal systems and the related costs within specific industries. Each system listed is specifically designed to cope with the disposal problem and available facilities of the individual plant shown. Therefore, drawing general conclusions about the relative costs of systems listed in the table would be erroneous. The disposal costs shown include capital charges and costs for labor and material. The disposal cost/ton will be higher the smaller the quantity of material, because capital charges for investment in facilities will remain the same regardless of quantity.

Fly ash, a residue from the combustion of coal and residual oil, probably is the most common material collected in emission control systems.

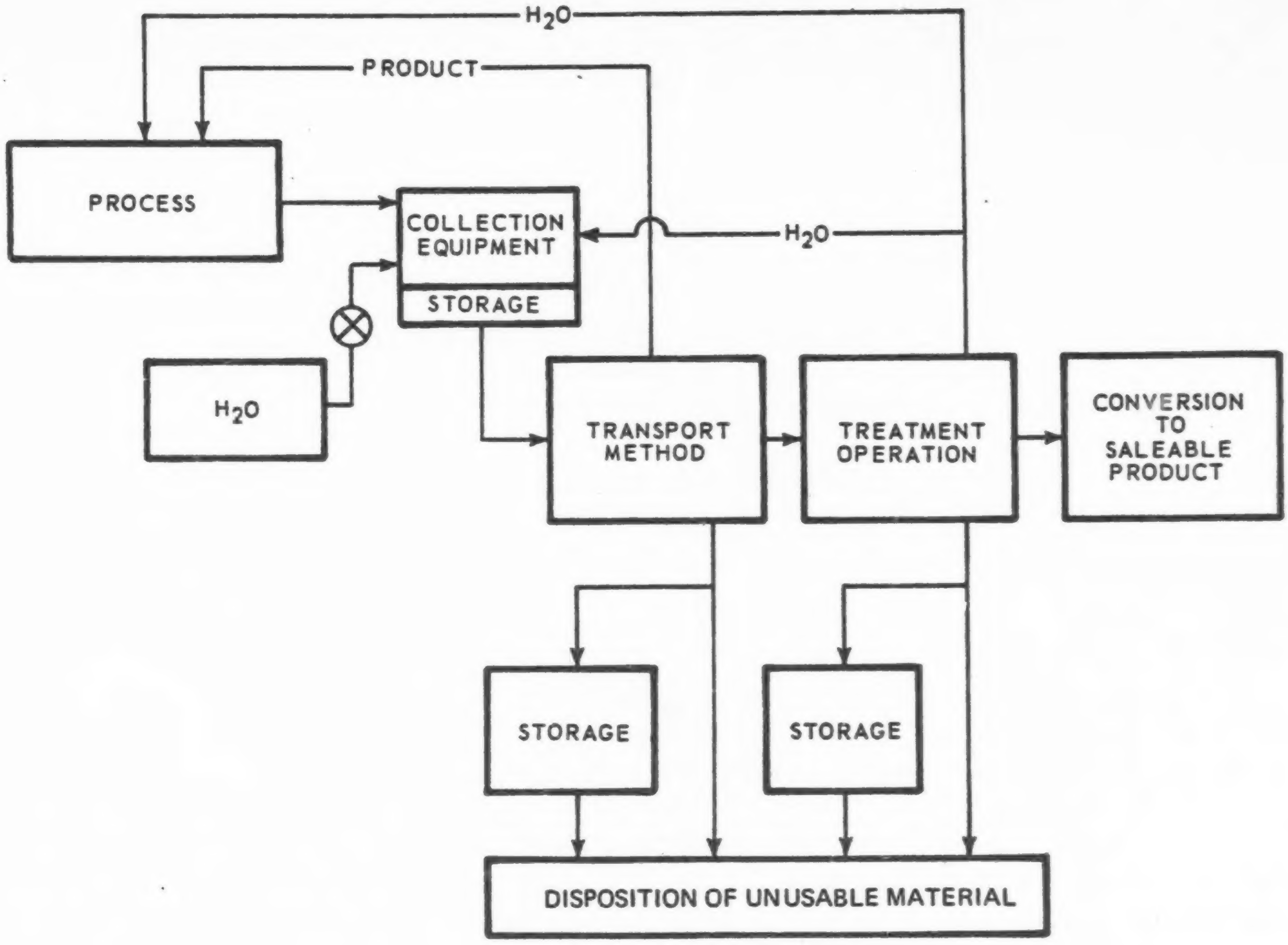


Figure A-25 - Flow Diagram for Disposal of Collected Particulate Material from Air Pollution Control Equipment

TABLE A-9

COSTS OF SPECIFIC DISPOSAL SYSTEMS

Industry	Collected Material	Treatment	Transport	Storage	Final Disposal	Cost estimate, (dollars/ton)
Power generation	Fly ash	Sedimentation	Pipeline	Settling pond	Landfill (sediment)	0.75
Power generation	Fly ash	-	Truck	Mound	Landfill	0.55
Power generation	Fly ash	-	Truck	Mound	City dump	1.10
Power generation	Fly ash	Form pellets	Vacuum system, truck, barge	Transfer bins, storage silo	Landfill or dump at sea	2.00
Power generation	Fly Ash	Form slurry	Pipeline	Settling pond	Landfill (sediment)	2.00
Power generation	Fly ash	Wetted	Pneumatic pipeline truck	Storage silo	Landfill	2.00
Power generation for chemical plant	Fly ash	Sedimentation	Pipeline	-	Lagoon	1.60
Power generation for chemical plant	Fly ash	-	Truck	Silos	Landfill	0.90
Chemical	-	Slurry (100,000 gal/day)	Barge	Tank	Dump at sea	3.00
Chemical	Weak acid (large volume)	-	Barge	Tank	Dump at sea	1.00
Power generation for pulp and paper	Fly ash	Sedimentation	Pipeline	-	Lagoon	2.30
Gray iron foundry	Cupola dust	Water clarification	Sediment by truck	Dempster dump	Landfill	1.40
Petroleum refining	Nondewatered sludge	-	Contract hauling	-	Landfill	4.75
Petroleum refining	Dewatered sludge	-	Contract hauling	-	Landfill	2.50
Petroleum refining	Sludge, filter coke, oily solids	-	Truck	-	In-plant landfill	20.00
Petroleum refining	Oily solids	-	Barge	-	Dump at sea	7.50
Petroleum refining	Catalyst fines	-	Contract hauling	-	Landfill	2.75
Portland cement	Waste dust	Slight wetting	Conveyor, truck	Bins	Landfill	1.05
Soaps and detergents	Suspended solids	-	Pipeline	-	Municipal treatment plant	2.50

An estimated 20 million tons of fly ash was produced in the United States in 1965. Only 3% of this total was sold as a marketable product.[12] If the cost for discarding the remaining 97% of the fly ash as unusable waste were $1.00/ton or more, this would represent a total cost of $20 million or more. Based on the data in Table A-9, a cost of $1.00/ton is a typical unit cost.

In certain situations, the disposal cost of fly ash can be a major portion of the total annualized cost for a complete pollution control system (including disposal facilities). For example, the disposal costs can be as high as 80% of the total annualized cost for an emission control system with older electrostatic precipitators which are no longer depreciated. The disposal cost still can be as high as 50% for similar systems with newly installed electrostatic precipitators, which usually have high depreciation charges.

Table A-10 shows a summary of fly ash disposal costs for material collected from electrostatic precipitators and mechanical collectors installed in electric utilities and is taken from a recent survey.[13] This survey analyzed the costs of disposal, the sales, and the uses of fly ash collected by 54 electric utilities and reported an average disposal cost of $0.74/ton. Analysis of the data for individual utilities revealed that disposal cost is partly a function of geographical location. The average disposal cost/ton in the heavily-populated East is higher than that reported elsewhere.

TABLE A-10

COST OF ASH DISPOSAL BY ELECTRIC UTILITIES

Type and Collection Method	Disposal Costs, Dollars/Ton Low	Medium	High
Fly ash (mechanical collector)	$0.15	$0.59	$1.67
Fly ash (electrostatic precipitator)	0.12	0.77	1.74
Bottom ash	0.15	1.04	4.76

A.8.4 Return of Collected Material to the Process

In some process operations, collected material is sufficiently valuable to warrant its return to the process. In these situations, the value of the recovered material can partially or wholly pay for the collection equipment. In many applications, however, the cost for the high efficiency control systems necessary to achieve desired ambient air quality will be greater than the revenue returned for recovery of the material collected. This is illustrated by the hypothetical example in Figure A-26.

The figure shows a linear relationship between collection efficiency and value of material recovered. It also shows a curvilinear relationship between collection efficiency and related equipment costs. Up to the break-even point D (which corresponds to an efficiency of about 97%), the recovery value of material collected is greater than the cost to achieve the recovery. Equipment designed for efficiencies greater than 97%, according to the curve, would have a higher cost than the potential recovery value.

If profit were the only control incentive, 85% collection efficiency would achieve the maximum profit, as illustrated by the profit line AB. If, however, emission standards made 97% collection efficiency necessary, no profit would be achieved at the break-even point D. For collection efficiency greater than 97%, equipment costs would exceed recovery costs. At 99% efficiency, for example, control equipment would cost the amount shown by FH, and the value recovered would be the amount GH. The difference FG would represent an expense and can be considered as the net control cost.

A survey conducted in 1956 shows that, out of 383 kilns, a total of 349 return collected dust to the process.[14/] Not only does recovered dust, in such situations, have value as a raw material, but its recovery also reduces disposal costs and decreases other related costs for the preparation of raw materials used in the process.

A.8.5 Recovery of Material for Sale

Although material collected by air pollution control equipment may be unsuitable for return to a process within the plant, it may be suitable for another manufacturing activity. Hence, it may be treated and sold to another firm that can use the material. Untreated pulverized fly ash, for example, which cannot be reused in a furnace, can be sold as a raw material to a cement manufacturer. It also can be used as a soil conditioner, or as an asphalt filler, or as landfill material. For such uses, pulverized fly ash requires no treatment and can be sold for as much as $1.00/ton. Pulverized fly ash which is treated can yield an even more valuable product. A limited number of utilities, for example, sinter pulverized fly ash to produce a lightweight aggregate which can be used to manufacture bricks and lightweight building blocks.

At the present time, however, the sale of raw or treated collected process material usually does not offer an opportunity to offset control costs to a significant extent.

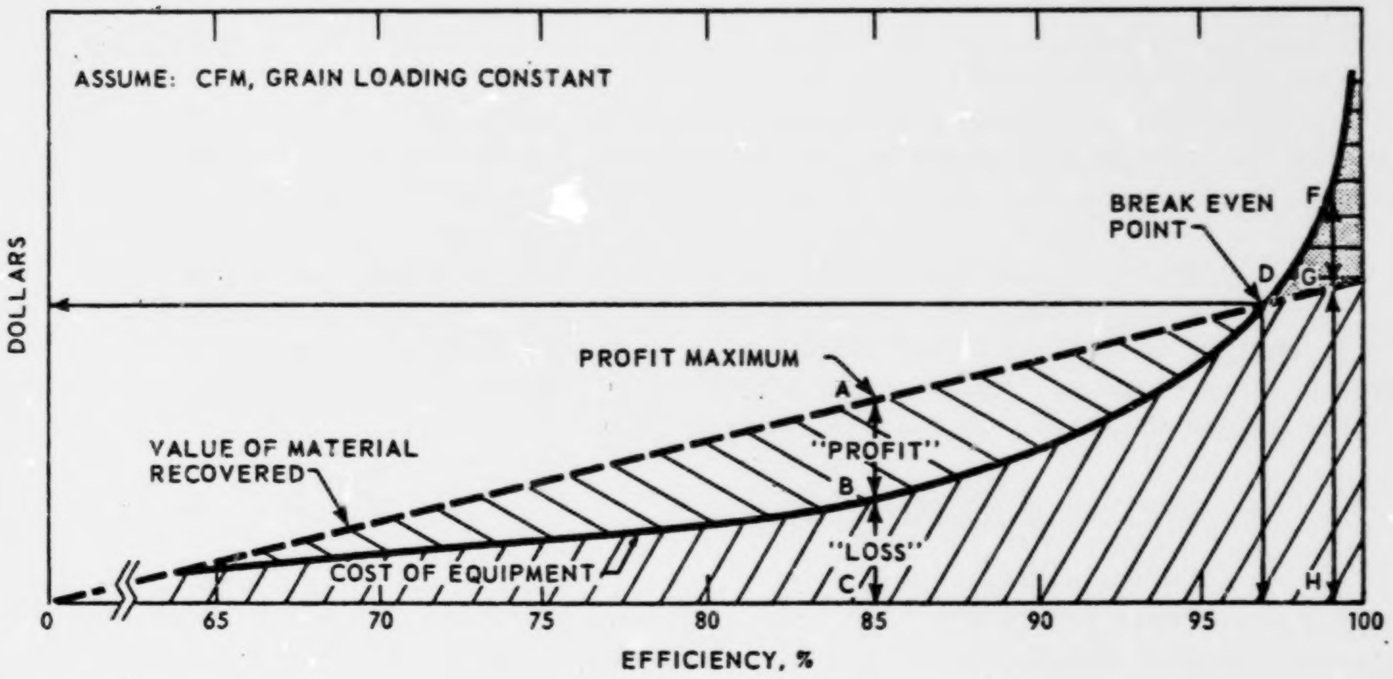


Figure A-26 - Theoretical Effect of Dust Value on Control Cost

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APPENDIX B

MINOR SOURCES

In addition to the data compiled on major industrial particulate pollutant sources discussed in Chapters 5-23, information of various types has been accumulated on several minor sources. Table B-1 presents emission factors and other assorted facts for these sources.

TABLE B-1

EMISSION FACTORS FOR MINOR SOURCES

Source of Particulate	Production (tons/yr)	Control Device	Emission Factor Range (lb/ton)	Average Emission Factor (lb/ton)
CHEMICAL PROCESS INDUSTRY				
Phenolic resin handling[4]				48
Pigment process[1]	--			
Grinder		water spray and oil filters		0.33*
Blender				1.9*
PVC Manufacturing[2]	1.1×10^6	FF		0.35*
Polypropylene manufacturing[2]	3.2×10^5			3.0
Rubber process[1]	2.7×10^6			
Mixer		baghouse		0.13*
Grinder		cyclones		~ 20 1.4*
FOOD INDUSTRY				
Coffee roasting	1.5×10^6			
Roaster[3]				
Direct fired		cyclone		7.6 2.2*
Indirect fired		cyclone		4.2 1.2*

TABLE B-1 (Continued)

Source of Particulate	Production (tons/yr)	Control Device	Emission Factor Range (lb/ton)	Average Emission Factor (lb/ton)
Coffee roasting (concluded)				
Stoner and cooler		cyclone		1.4 0.4*
Instant Coffee				
Spray dryer		cyclone + wet scrubber		1.4*
Roaster[1/]		cyclone		1.9*
Coffee/tea processing[1/]	$7. \times 10^4$ ǂ			
Roaster		cyclone		3.1*
Citrus plants[1/]				
Peel dryer			1.8 - 9.6	5.0*
Orange pulp dryer				75.3
MINERAL PRODUCTS INDUSTRY				
Abrasive grit manufacturing[1/]		baffle sedimentation chamber		0.11*
Blast grit and roofing[1/]				
Granule manufacturing				
Dryer		cyclone		0.42*
Screens		cyclone		4.1*
Calcium carbide manufacturing[3/]	9.2×10^5			
Coke dryer		cyclone + spray dryer		0.2*
Electric furnace hood				1.7
Furnace room vents				2.6
Main stack		impingement scrubber		2.0*
Concrete batching[1/]				5.2
Fiberglas manufacturing[2/]				
Melting furnace				
Regenerative			1 - 4	3
Recuperative			0.5 - 1	1
Forming line			23.5 - 100	62
Curing oven			3.4 - 14	6.9
Frit manufacturing				
Rotary melter[1/]				17
Reverberatory furnace[3/]			5.9 - 45.5	16.5

TABLE B-1 (Continued)

Source of Particulate	Production (tons/yr)	Control Device	Emission Factor Range (lb/ton)	Average Emission Factor (lb/ton)
MINERAL PRODUCTS INDUSTRY (Concluded)				
Glass manufacturing				
Furnace3/				2
Reverberatory furnace1/				3
Furnace1/			1.5 - 7.9	3
Furnaces1/			0.02 - 1.1	0.31
Ground brick plant1/				120
Gypsum board manufacturing				
Grinder1/		ESP	0.14 - 0.24	0.19*
Trim saw4/			lb/350 ft^2	
Gypsum manufacturing2/				
Dryer		FF		22
		cyclone + ESP	4 - 40 (2)	0*, 0.2*
Grinder		FF		1
				neg.*
Calciner		FF		90
				0.1*
Conveyor		FF		0.7
				neg.*
Magnesite plant1/				430
Perlite manufacturing3/	4.1 x 10^5			
Furnace				21
Plaster of Paris manufacturing1/		ESP		0.9*
Quartz plant1/		(3)	7.8 - 9.5	8.6*
Rock wool manufacturing3/				
Cupola			16 - 28	21.6
Reverberatory furnace				4.8
Blow chamber			4 - 56	21.6
Curing oven			1.5 - 5.9	3.6
Cooler			0.4 - 5.5	2.4
Cupola1/				32.4

TABLE B-1 (Concluded)

Source of Particulate	Production (tons/yr)	Control Device	Emission Factor Range (lb/ton)	Average Emission Factor (lb/ton)
MISCELLANEOUS				
Electric arc welding[1]				0.01 - 0.02 lb/lb electrode
Soldering[1]				0.005 lb/lb solder
Plywood manufacturing[5]				
Dryer				0.51
Mercury smelting[6]				40.0

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* Controlled emission factor based on indicated control device.

ǂ Tea production only.

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